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THERMAL MODEL OF LASER-INDUCED SKIN DAMAGE: COMPUTER PROGRAM OPERATOR'S MANUAL

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NOTICES

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The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act of 1970 and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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A user-oriented description is given of a computer program for predicting temperature rises, irreversible damage and degree of burns caused to skin by laser exposures. This report describes the parameters necessary to run the program and provides suggested values for the parameters. Input data are described in detail as well as the capabilities and limitations of the program.

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INTRODUCTION

The Skin Model is a mathematical model that predicts the extent of thermal damage and degree of burn produced in skin by laser radiation. The model was developed by IIT Research Institute and is a result of many years of improvements in thermal damage modeling techniques. The mathematical basis for temperature predictions is the following heat-conduction equation in cylindrical coordinates:

$$\rho C\frac{\partial v}{\partial t} = \bar{q}(r,z,t) + \frac{K}{r}\frac{\partial v}{\partial r} + \frac{\partial}{\partial r}\left(K\frac{\partial v}{\partial r}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial v}{\partial z}\right) \tag{1}$$

$$- \bar{B}(z)C_b - \bar{\bar{q}}(r,z,t)$$

where ρ = density of tissues, g/cm^3

C = specific heat of tissues, cal/g-°C

$\bar{B}$ = blood flow, g/cm^3-sec

C_b = specific heat of blood, cal/g-°C

K = thermal conductivity, cal/cm-sec-°C

$\bar{q}$ = rate of heat deposition from laser, cal/cm^3-sec

$\bar{\bar{q}}$ = rate of heat loss in transforming water into steam, cal/cm^3-sec

r = radial distance, cm

t = time, sec

v = temperature, °C

z = axial distance, cm

In addition, equations presented on the next page provide for:

- heat losses to the ambient air,
- steam blisters, and a
- hair follicle.

Initially, the skin is considered to be at a uniform temperature measured with respect to the surrounding air. Biological heating is neglected. Irradiation from the laser is reduced as a consequence of interceptions of radiation by hairs and reflection from the surface of the skin. In this regard internal reflections are considered to occur at the surface.

Once the radiation enters the skin its intensity, q, is attenuated according to Beer's Law, namely

$$q(r,z,t) = q(r,0,t)\exp\left(-\int_0^z \mu(z)dz\right) \qquad (2)$$

where q = radiant intensity considered as a step function in time, cal/cm^2-sec

μ = absorption coefficient considered as a step function with respect to depth z, 1/cm.

Beam divergence is neglected. Equation 2 is then used to determine the rates of energy deposition $\bar{q}(r,z,t)$ for equation 1.

Blood flow B, specific heat C, density ρ, and thermal conductivity K are considered to vary with respect to depth. Blood flows remain constant with respect to time and act as a heat sink. Blood is not treated as a means of heat transfer. Thermal properties and density vary with the amount of water in the tissues.

When water commences to boil, the resultant water vapor is allowed to escape from a given depth of skin. Resultant rates of heat loss $\bar{q}$ per unit volume are then introduced into equation 1. Additional heat losses are allowed to occur from the surface of the skin by natural convection/radiation. These losses are described by

$$-K\frac{\partial v}{\partial z}\Big|_{z=0} = Hv\Big|_{z=0} \qquad (3)$$

where H = heat-transfer coefficient, cal/cm^2-sec-°C.

This coefficient is assigned values according to whether or not sweat is initially present. The coefficient is not changed with time.

Following water evaporation, densities, specific heats, and thermal conductivities are decreased according to the amount of water lost at specific locations. In addition a steam blister is allowed to form at the base of the epidermis provided it reaches the temperature DTEMP. Once a blister forms, thermal resistance is introduced to account for the presence of water vapor.

Mathematically this is given by

$$-K\frac{\partial v}{\partial z}\Big|_{z_w-\delta} = -K\frac{\partial v}{\partial z}\Big|_{z_w+\delta} = H_w\left(v\Big|_{z_w-\delta} - v\Big|_{z_w+\delta}\right). \qquad (4)$$

This equation neglects the heat capacity of the water vapor so that heat fluxes crossing the two blister surfaces are identical. These fluxes are expressed by the product of the heat-transfer coefficient H_w across the blister and the temperature difference between the surfaces. Depth of blister formation is described by z_w, and [illegible] represents a vanishingly small displacement of the upper and lower blister surfaces.

The model provides a hair follicle at a given depth on the axis of the laser beam. Radiation is considered to be entirely absorbed by the follicle. Heat deposition rates directly below the follicle are zero.

The heat-conduction equation is approximated by finite differences and then solved with an explicit-implicit alternating-direction technique developed by D. W. Peaceman and H. H. Rachford (1). This technique solves the finite-difference equations explicitly in z and implicitly in r for odd time steps, and implicitly in z and explicitly in r for even time steps. In explicit calculations, existing temperatures are used to represent thermal gradients; in implicit calculations, future temperatures are used. This approach results in a set of equations that are solved using ordinary matrix algebra. Larger time intervals can be used with this technique than with standard explicit finite-difference methods.

The model uses the predicted temperature rises to determine irreversible tissue damage by applying Henrique's damage equation for temperatures above a given value:

$$\Delta\Omega(r,z,t) = C_1 \exp[C_2/T_a(r,z,t)]\Delta t \qquad (5)$$

where $\Delta\Omega(r,z,t)$ = incremental damage at point r, z

C_1 and C_2 = constants given by array DAM in nomenclature

$T_a(r,z,t)$ = absolute temperature

Δt = increment of time.

Irreversible tissue damage is defined as occurring whenever the integral of $\Delta\Omega$ over time is greater than or equal to 1. From this mathematical basis, the model has the capability of predicting temperature rises, damage thresholds, the extent of damage within the skin, and degree of burn based upon the resultant Ω values and peak temperatures.

1. Peaceman, D. W., and H. H. Rachford, Jr. The numerical solution of parabolic and elliptic differential equations. J Soc Indust Appl Math 3:28-41 (1955).

Designed for maximum flexibility, the model offers wide variability in characterizing tissues and laser exposures. It accommodates variations in laser radiation characteristics and in optical, thermal, and physiological properties of the skin. The model's design enables the user to print out only those portions of the output information which he desires.

The purpose of this manual is to give the user a basic understanding of the model's capabilities and how to use it within the limits of those capabilities. Additional information on the code can be obtained from the IITRI Technical Report, "Laser-Induced Thermal Damage of Skin" (2).

The manual briefly describes (1) the capabilities and limitations of the model as they pertain to the source, the skin, the mechanics of the program, and the output desired; and (2) the basic input required, listing the required cards, their order, and appropriate formats and options available to the user in regard to printed output. Appendix A presents a glossary of all input parameters.

CAPABILITIES AND LIMITATIONS

The user is responsible for adequately describing the exposure conditions to be modeled. He must describe the incident radiation, the media, the mechanics (temporal and spatial grid) of the program, and the output desired. This section presents a broad overview of the capabilities and limitations as they pertain to these areas.

In developing the program, several major assumptions are made. First, the skin geometries are simulated in cylindrical coordinates. Second, all reflections occur at the surface of the skin. Third, beam profiles are identical at all depths within the skin, and are radially symmetric. Fourth, thermal properties change only with water loss and not with temperature. Fifth, blood flows act solely as a heat sink. Sixth, steam blisters remain intact, while water beneath the blisters becomes a superheated liquid without deforming tissues.

The model has a number of features which give the user flexibility in describing the incident radiation in terms of its spatial, spectral, and temporal properties. The spatial profile of the beam may be designated as uniform, gaussian, or irregular. For uniform or gaussian profiles, the user

[2] Takata, A. N. Laser-induced thermal damage of skin. SAM-TR-77-38, December 1977.

specifies the beam radius and the incident power. For irregular profiles, the user constructs the desired beam profiles by specifying the incident power and the relative intensities and associated radial distances from the center of the beam.

Temporal variations of the incident radiation are specified by selecting the duration of the pulses, the repetition rates and intensity, and the number of pulses. The model assumes all pulses to be square with respect to time. However, temporally varying pulses can be constructed from a collection of back-to-back square-shaped pulses. The pulses and repetition rates may be considered identical (noncoded) or variable (coded). In that the model only predicts thermal damage, pulse durations should exceed 10^{-}[illegible] seconds. For shorter pulse durations, other damage mechanisms may predominate.

Skin media are described in terms of optical, thermal, and physiological characteristics. The optical parameters include coefficients for absorption and reflection. Thermal parameters include heat capacity, thermal conductivity, and blood flow associated with individual skin and subcutaneous layers plus their initial temperature. The skin is considered to be composed of two layers, namely the epidermis and dermis. A single homogeneous layer is used to represent subcutaneous tissues.

Initially, the thermal properties and density are constant within the dermis and within the subcutaneous tissues and vary linearly across the epidermis. Optical properties and blood flow rates are constant across layers which are not necessarily coincident with the epidermis or dermis.

The model automatically selects the time steps. However, the user specifies the size of the increments for the spatial grid in the skin media. The dimensions of the spatial and temporal increments represent the limits of resolution of the model predictions. The spatial grid has uniform increments in the region of highest temperature rise and constantly expanding increments away from the highest temperature regions. The temporal grid has constantly expanding time steps from the beginning and end of each pulse.

The user selects the range of spatial coordinates used to print the temperature rises and damage. Also, the user has the option to print and plot temperature rises at any selected time. A separate plotting routine uses input data cards

punched by the model and user control cards to plot the temperature rises. This program is described in Reference 3.

INPUT REQUIREMENTS

This section describes the input required to specify the source, skin media, the mechanics of the program, and output desired. All parameters required by the user as input are defined in Appendix A. Program listing is presented in Appendix B. When solving a problem, the user must describe the incident radiation, and must also specify the parameters governing the mechanical operation of the program, such as the size of the grid required and the output desired.

To simulate the radiation incident on the skin media, the user has the option of specifying a uniform-, gaussian-, or irregular-beam irradiance profile. Axial symmetry for all beam profiles is assumed. For uniform-beam profiles, the beam radius (RUNIF) must be specified. For gaussian-beam profiles, RIM must be specified at a particular relative intensity point (CUT). For irregular-beam profiles, the absolute or relative irradiance profile must be specified on a point-by-point basis by listing the irradiance value, PX(L), at the radial distance, RX(L), from the center of the beam. The total number of specified irradiance points is equal to LR. The model will integrate the beam profile at radial intervals (RINT), to arrive at a series of constant intensities centered about each radial grid point.

The model can treat coded pulses which differ in intensity and duration or noncoded pulses which are identical as are the times between pulses. Coded pulses are considered to follow one another with no elapsed time between pulses. Single pulses are considered as noncoded. Data cards required for programming are described in Table 1. Further information is presented at the bottom of Table 1.

Input cards are read in sequence according to the card numbers presented in the listing and Table 1. This table summarizes the format statements along with the input parameters.

All cards cited in Table 1, except for card number 21 and those followed by letters, are needed for each computer

3. [illegible], A. R., et al. Retinal thermal model of laser-induced eye damage. Program operators manual. SAM-TR-76-33 (1976).

TABLE 2. INPUT DECK

Card No.	Format	Parameters
1	I7,10E7.3	LB,ABSW,CON1,CON2,SH0,SH1,SH2,W0,W1,W2,W3
2	10E7.3	D0,D1,D2,D3,ZBL,NW,DTEMP,DHF,SHF
3	10F7.4	TBL(L),L=1,LB
4	10F7.4	CB,(B(L),L=1,LB)
5	10F7.4	TSWEAT,DEPID,TEPID,TDERM,TO,TE,ZDEP
6	10F7.4	DAM(1,1),DAM(1,2),DAM(2,1),DAM(2,2)
7	10F7.4	TBL(L),L=1,27
8	I7,10E7.3	LZ,ABSC,N1,N2,NAIR,REF
9	10F7.4	TH(L),L=1,LZ
10	10F7.4	ABS(L),L=1,LZ
11	10I7	IPROF,MK
12,UNIF[a]	F7.4,2I7	RUNIF,N1,N
12,GAUSS[a]	2F7.4,2I7	RIM,CUT,N1,N
12,IRREG[a]	10I7	LR,N1,N
12,IRREG[a]	10E7.3	RX(L),L=1,LR
12,IRREG[a]	10E7.3	PX(L),L=1,LR
13	4F7.1,4I7	WAVEL,XC,ZR,ZZ,LASER,NPULSE,NGX,NTX
14,NC,1[b]	I7,10E7.3	NTP,DPULSE,POWX
14,NC,X[b]	I7,10E7.3	REPET,DPULSE,POWX
12,NC,GP[b]	10I7	NG
14,NC,GP[b]	10I7	NPG(L),L=1,NG
14,NC,GP[b]	10I7	NPR(L),L=1,NG
14,CODED[b]	10I7	NTP
14,CODED[b]	10E7.3	DPULSC(L),L=1,NPULSE
14,CODED[b]	10E7.3	POWERC(L),L=1,NPULSE
15	10I7	M
16	10I7	ID1,ID2,JD1,JD2,ITYPE,KTYPE,KX
17	10E7.3	TIME1(L),L=1,KX
18	10E7.3	TIME2(L),L=1,KX
19	I7,10E7.3	NW,(ZW(L),L=1,NW)
20	10E7.3	DB1,DB2,DB3,DB5
21	I7	II1,II2,II3,JJ1,JJ2

[a]Only use card with designated profile.

[b]For single-pulse exposures use card 14,NC,1, for multiple noncoded pulses use cards 14,NC,X, for multiple noncoded pulses to be grouped use card 14,NCX, and cards 14,NC,GP (see text). For coded pulses use cards 14,CODED.

run. Card 21 is required only when one wishes to punch temperature rises on cards. The other exceptions are cards 12.... (beam profile), and cards 14....(pulse modulation). For uniform profiles use card 12, UNIF; for gaussian profiles use card 12, GAUSS; and for irregular profiles use card 12, IRREG. A description of the cards 14.... needed for describing pulse characteristics is presented at the bottom of Table 1. In this regard, provisions have been made to minimize computer execution times caused by long noncoded pulse trains. This provision is optional and requires use of cards 14, NC, CP. These cards result in the replacement of various sets of consecutive pulses by a "single pulse" which extends from the start of a given pulse to the start of the pulse immediately following each set of consecutive pulses. Power is set equal to the total energy associated with the pulses divided by the duration of the "single pulse." By this means total energy is conserved. Resultant power is termed mean power.

To introduce mean powers into long pulse trains, one should first select several sets of pulses spaced at regular intervals along the length of the pulse train with at least two individual pulses between the sets of pulses and at the end of the train. Incremental damage is only predicted during individual pulses following the first of each series of individual pulses. Weighting factors are used to account for damage produced during remaining pulses.

An example of the above procedure is shown in Figure 1. Here we have chosen a pulse train consisting of 40 pulses. Number of pulses replaced by mean powers is indicated by numbers over the shaded area. Table 2 presents the values needed for the arrays NPG(L) and NPR(L) to structure the 40 pulses in the fashion illustrated by Figure 1.

TABLE 2. PROGRAMMING 40 PULSES IN MANNER ILLUSTRATED BY FIGURE 1

L	NPG(L)	NPR(L)	L	NPG(L)	NPR(L)
1	2	0	12	1	7
2	1	0	13	5	0
3	1	7	14	1	0
4	5	0	15	1	7
5	1	0	16	3	0
6	1	7	17	1	0
7	5	0	18	1	2
8	1	0	19	1	1
9	1	7	20	1	1
10	5	0	21	1	1
11	1	0		40	40

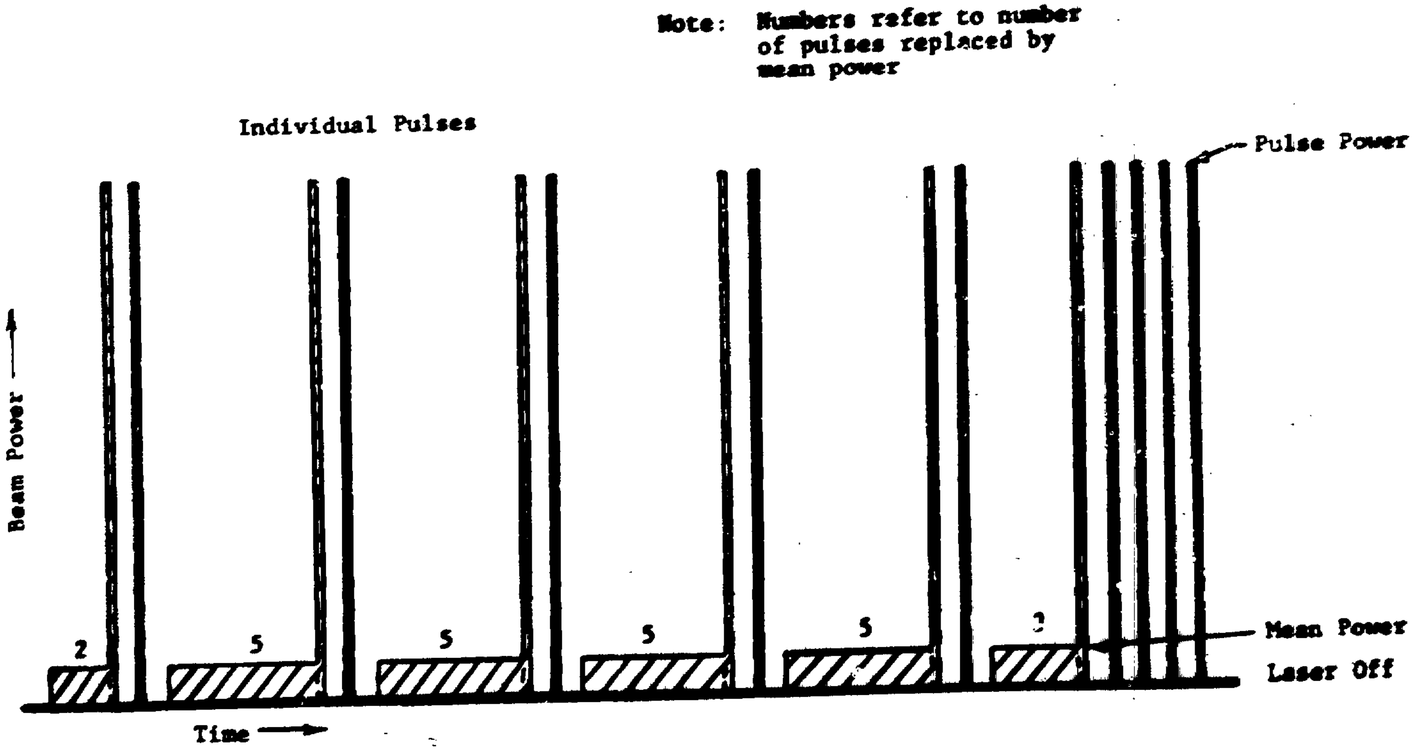

Figure 1. Structuring pulse train (40 pulses) using mean power to conserve execution time.

The index L indicates the order in which individual pulses or mean powers are to be considered. The array NPG(L) represents both the number of pulses and how they are to be treated. For normal treatment of pulses, NPG(L) is set equal to 1. NPG(L) values greater than 1 result in replacement of the specified number of pulses by the mean laser power.

The array NPR(L) represents the number of pulses represented by individual pulses shown as shaded in Figure 1. These pulses have L values of 3, 6, 9, 12, and 15 in Table 2. Each of these pulses represents 6 additional pulses--three immediately preceding it and three immediately following it. All other NPR values should be zero. The sum of the two arrays NPG and NPR should equal the total number of pulses in the train.

Thicknesses of the epidermis and dermis will vary widely with individual and location. Epidermal thicknesses for humans range from about 0.005 to about 0.015 cm while dermal thicknesses range from about 0.15 to 0.30 cm. Recommended values presented in the Glossary represent average values for pig skin.

Optical property data are presented in Table 3. These data were acquired from several sources as indicated in reference 2. For those coefficients not presented in the table, use the coefficients for water given in Table 4. These values are not critical in that at long wavelengths much of the irradiation is deposited within shallow depths of the epidermis for which coefficients are known. Recommended values for the remaining input are presented in Table 5 and Appendix A.

Table 6 is presented to assist the user in identifying parameters requiring change in altering various features such as wavelength, laser profile and pulses, and skin.

TABLE 3. OPTICAL PROPERTIES OF HUMAN SKIN (ref.2)

Wavelength (μm)	Reflection (%) White	Reflection (%) Negro	Absorption coefficients (normal tissues), 1/cm: Water	Outer 0.003 cm of epidermis	Remaining skin	Fat	Absorption coefficients (irreversibly damaged tissues), 1/cm
.33	(35)	-	0	200	40	22	53
.40	22	9	0	110	21	20	39
.50	38	10	0	55	13	13	19
.60	38	12	0	29	12	12	15
.65	37	15	0	25	8	11	12
.70	68	22	0	40	9	10	12
.80	67	37	0	16	10	10	10
.90	57	39	0	13	12	10	10
1.00	53	38	0	238	13	10	10
1.10	58	40	0	231	13	10	10
1.20	58	40	1	233	12	12	12
1.42	35	27	1	217	31	24	34
1.70	13	11	7	231	20	27	25
1.85	11	9	23	205	40	28	35
2.20	3	3	17	202	30	23	43
2.40	3	3	30	244	50	28	54
3.00	2	2	11394	1448	-	-	-
4.00	2	2	145	380	-	-	-
4.7	2	2	420	372	-	-	-
5.00	2	2	312	401	-	-	-
6.00	2	2	2241	1230	-	-	-
7.00	1	1	574	999	-	-	-
8.00	1	1	539	921	-	-	-
9.00	1	1	537	821	-	-	-
10.00	1	1	638	727	-	-	-
11.00	1	1	1106	911	-	-	-

TABLE 4. ABSORPTION CONSTANTS OF WATER (ref. 4)

λ(µm)	α(cm^{-1})	λ(µm)	α(cm^{-1})	λ(µm)	α(cm^{-1})
0.200	$6.9115 \cdot 10^{-2}$	0.900	$6.7858 \cdot 10^{-2}$	3.400	$7.2072 \cdot 10^{2}$
0.225	$2.7367 \cdot 10^{-2}$	0.925	$1.4400 \cdot 10^{-1}$	3.450	$4.8080 \cdot 10^{2}$
0.250	$1.6839 \cdot 10^{-2}$	0.950	$3.8757 \cdot 10^{-1}$	3.500	$3.3750 \cdot 10^{2}$
0.275	$1.0739 \cdot 10^{-2}$	0.975	$4.4852 \cdot 10^{-1}$	3.600	$1.7977 \cdot 10^{2}$
0.300	$6.7021 \cdot 10^{-3}$	1.000	$3.6317 \cdot 10^{-1}$	3.700	$1.2227 \cdot 10^{2}$
0.325	$4.1759 \cdot 10^{-3}$	1.200	1.0357	3.800	$1.1244 \cdot 10^{2}$
0.350	$2.3338 \cdot 10^{-3}$	1.400	$1.2387 \cdot 10^{+1}$	3.900	$1.2244 \cdot 10^{2}$
0.375	$1.1729 \cdot 10^{-3}$	1.600	6.7152	4.000	$1.4451 \cdot 10^{2}$
0.400	$5.8434 \cdot 10^{-4}$	1.800	8.0285	4.100	$1.7225 \cdot 10^{2}$
0.425	$3.8438 \cdot 10^{-4}$	2.000	$6.9115 \cdot 10^{+1}$	4.200	$2.0585 \cdot 10^{2}$
9.450	$2.8484 \cdot 10^{-4}$	2.200	$1.6508 \cdot 10^{+1}$	4.300	$2.4694 \cdot 10^{2}$
0.475	$2.4736\ 10^{-4}$	2.400	$5.0056 \cdot 10^{+1}$	4.400	$2.9417 \cdot 10^{2}$
0.500	$2.5133 \cdot 10^{-4}$	2.600	$1.5321 \cdot 10^{+2}$	4.500	$3.7420 \cdot 10^{2}$
0.525	$3.1595 \cdot 10^{-4}$	2.650	$3.1772 \cdot 10^{2}$	4.600	$4.0158 \cdot 10^{2}$
0.550	$4.4782 \cdot 10^{-4}$	2.700	$8.8430 \cdot 10^{2}$	4.700	$4.1977 \cdot 10^{2}$
0.575	$7.8676 \cdot 10^{-4}$	2.750	$2.6961 \cdot 10^{3}$	4.800	$3.9270 \cdot 10^{2}$
0.600	$2.2829 \cdot 10^{-3}$	2.800	$5.1612 \cdot 10^{3}$	4.900	$3.5135 \cdot 10^{2}$
0.625	$2.7948 \cdot 10^{-3}$	2.850	$8.1571 \cdot 10^{3}$	5.000	$3.1165 \cdot 10^{2}$
0.650	$3.1706 \cdot 10^{-3}$	2.900	$1.1613 \cdot 10^{4}$	5.100	$2.7350 \cdot 10^{2}$
0.675	$4.1516 \cdot 10^{-3}$	2.950	$1.2694 \cdot 10^{4}$	5.200	$2.4408 \cdot 10^{2}$
0.700	$6.0139 \cdot 10^{-3}$	3.000	$1.1394 \cdot 10^{4}$	5.300	$2.3236 \cdot 10^{2}$
0.725	$1.5860 \cdot 10^{-2}$	3.050	$9.8883 \cdot 10^{3}$	5.400	$2.3969 \cdot 10^{2}$
0.750	$2.6138 \cdot 10^{-2}$	3.100	$7.7830 \cdot 10^{3}$	5.500	$2.6504 \cdot 10^{2}$
0.775	$2.3998 \cdot 10^{-2}$	3.150	$5.3856 \cdot 10^{3}$	5.600	$3.1865 \cdot 10^{2}$
0.800	$1.9635 \cdot 10^{-2}$	3.200	$3.6285 \cdot 10^{3}$	5.700	$4.4754 \cdot 10^{2}$
0.825	$2.7722 \cdot 10^{-2}$	3.250	$2.3586 \cdot 10^{3}$	5.800	$7.1498 \cdot 10^{2}$
0.850	$4.3317 \cdot 10^{-2}$	3.300	$1.4013 \cdot 10^{3}$	5.900	$1.3248 \cdot 10^{3}$
0.875	$5.6154 \cdot 10^{-2}$	3.350	$9.7905 \cdot 10^{2}$	6.000	$2.2410 \cdot 10^{3}$

4. Hale, G. M. and M. R. Querry. Optical constants of water in the 200 nm to 200 µm wavelength region. Appl Optics 12(3): 555-564 (1973).

TABLE 4. (Continued)

$\lambda(\mu m)$	$\alpha(cm^{-1})$	$\lambda(\mu m)$	$\alpha(cm^{-1})$	$\lambda(\mu m)$	$\alpha(cm^{-1})$
6.100	$2.6987\cdot10^3$	9.800	$6.1421\cdot10^2$	27.000	$1.6011\cdot10^3$
6.200	$1.7836\cdot10^3$	10.000	$6.3837\cdot10^2$	28.000	$1.5169\cdot10^3$
6.300	$1.1370\cdot10^3$	10.500	$7.9228\cdot10^2$	29.000	$1.4430\cdot10^3$
6.400	$8.8161\cdot10^2$	11.000	$1.1058\cdot10^3$	30.000	$1.3739\cdot10^3$
6.500	$7.5785\cdot10^2$	11.500	$1.5517\cdot10^3$	32.000	$1.2734\cdot10^3$
6.600	$6.7782\cdot10^2$	12.000	$2.0839\cdot10^3$	34.000	$1.2160\cdot10^3$
6.700	$6.3207\cdot10^2$	12.500	$2.6038\cdot10^3$	36.000	$1.1973\cdot10^3$
6.800	$6.0430\cdot10^2$	13.000	$2.9483\cdot10^3$	38.000	$1.1938\cdot10^3$
6.900	$5.8643\cdot10^2$	13.500	$3.1928\cdot10^3$	40.000	$1.2095\cdot10^3$
7.000	$5.7446\cdot10^2$	14.000	$3.3211\cdot10^3$	42.000	$1.2237\cdot10^3$
7.100	$5.6637\cdot10^2$	14.500	$3.3626\cdot10^3$	44.000	$1.2452\cdot10^3$
7.200	$5.6025\cdot10^2$	15.000	$3.3678\cdot10^3$	46.000	$1.2621\cdot10^3$
7.300	$5.5430\cdot10^2$	15.500	$3.3564\cdot10^3$	48.000	$1.2776\cdot10^3$
7.400	$5.5020\cdot10^2$	16.000	$3.3144\cdot10^3$	50.000	$1.2918\cdot10^3$
7.500	$5.4622\cdot10^2$	16.500	$3.2596\cdot10^3$	60.000	$1.2294\cdot10^3$
7.600	$5.4234\cdot10^2$	17.000	$3.1712\cdot10^3$	70.000	$1.0340\cdot10^3$
7.700	$5.4019\cdot10^2$	17.500	$3.0806\cdot10^3$	80.000	$8.5922\cdot10^2$
7.800	$5.3971\cdot10^2$	18.000	$2.9740\cdot10^3$	90.000	$7.4840\cdot10^2$
7.900	$5.3924\cdot10^2$	18.500	$2.8597\cdot10^3$	100.000	$6.6853\cdot10^2$
8.000	$5.3878\cdot10^2$	19.000	$2.7382\cdot10^3$	110.000	$6.0661\cdot10^2$
8.200	$5.3790\cdot10^2$	19.500	$2.6035\cdot10^3$	120.000	$5.5083\cdot10^2$
8.400	$5.4006\cdot10^2$	20.000	$2.4693\cdot10^3$	130.000	$4.9686\cdot10^2$
8.600	$5.4357\cdot10^2$	21.000	$2.2859\cdot10^3$	140.000	$4.4880\cdot10^2$
8.800	$5.4978\cdot10^2$	22.000	$2.1306\cdot10^3$	150.000	$4.1469\cdot10^2$
9.000	$5.5711\cdot10^2$	23.000	$2.0052\cdot10^3$	160.000	$3.8956\cdot10^2$
9.200	$5.6685\cdot10^2$	24.000	$1.8902\cdot10^3$	180.000	$3.4837\cdot10^2$
9.400	$5.7886\cdot10^2$	25.000	$1.7895\cdot10^3$	190.000	$3.3136\cdot10^2$
9.600	$5.9429\cdot10^2$	26.000	$1.6916\cdot10^3$	200.000	$3.1667\cdot10^2$

TABLE 5. TBL(L) VALUES (ref. 5)

L[a]	TBL(L), °C	L	TBL(L), °C	L	TBL(L), °C
1	100.0	10	179.0	19	208.8
2	119.6	11	183.2	20	211.4
3	132.9	12	187.1	21	213.9
4	142.9	13	190.7	22	216.2
5	151.1	14	194.1	23	218.5
6	158.1	15	197.4	24	220.8
7	164.2	16	200.4	25	222.9
8	169.5	17	203.4	26	225.0
9	174.5	18	206.1	27	227.0

[a]Index L indicates atmospheres of pressure caused by temperature TBL(L).

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5. Handbook of Chemistry, Sandusky, Ohio; Handbook Publishers, Inc.

TABLE 6. INPUT PARAMETERS CATALOGED ACCORDING TO DEPENDENCE

Parameters	Exposure: Wavelength	Exposure: Profile	Exposure: Pulses	Skin thickness	Tissue properties	Grid	Time steps	Printing	Miscellaneous[b]
ABS(L),L=1,LZ	a				a				
ABSC	a				a				
ABSW	a				a				
BL(I),I=1,10					a				
CON1,CON2					a				
CUT		a							
DBW(L1,L2									1
DB1, DB2, DB3, DB5									2
DEPID				a					
DWF									3
EPULSE(I),I=1, NPULSE			a						
EPULSE			a						
DTEMP									4
D0,D1, D2,D3									
HAIR									5
HW									6
H1,H2									6
ID1,ID2								a	
II1,II2,II3								a	
IPROF		a							
ITYPE								a	
JD1,JD2								a	
JJ1,JJ2								a	
KTYPE								a	
KX								a	
LASER			a						
LB									1
LR			a						
LZ	a								
M						a			
MK							a		
N						a			
NC			a						
NCX			a						
NPC(L),L=1, NC			a						
NPR(L),L=1, NC			a						
NPULSE			a						
NTP							a		
NTX							a		

TABLE 6. (Continued)

Parameters	Exposure: Wavelength	Exposure: Profile	Exposure: Pulses	Skin thicknesses	Tissue properties	Grid	Time steps	Printing	Miscellaneous[b]
NW						a			7
NI									
POWERC(L),L=1, NPULSF			a						
POWR			a						
PR(L),L=1,LR		a							
RRT	a								
REPFT			a						
RIN		a							
RUNIF		a							
RR(L),L=1,LP		a							
SHF									3
SK0,SK1,SK2					a				
TB(L),L=1,LB					a				
TBL(L),L=1,27									8
TDERM				a					
TE									9
TEPID				a					
TH(L),L=1,LZ	a				a				
TIME1(L),L=1,KK								a	
TIME2(L),L=1,KK								a	
TO									9
TWHEAT									9
WAVEL	a								
W0,W1,W2,W3					a				
XC							a		
XBL									4
ZDEP									10
XR							a		
ZW(L),L=1,NW									7
ZZ							a		

[a]Dependent parameter/function

[b]Numbers described below:

1 - rates of thermal damage
2 - criteria for degree of burns
3 - hair follicles
4 - steam blisters
5 - hair covering
6 - heat-transfer coefficients
7 - calculation of heat losses from escaping steam
8 - steam pressures
9 - initial temperatures
10 - depth from which steam escapes

APPENDIX A

GLOSSARY OF INPUT PARAMETERS

ABS(L),L=1,LZ--Absorption coefficients of undamaged skin and subcutaneous tissues. Coefficients vary with wavelength and are considered constant in each of LZ layers of thicknesses TH(L).

Units. 1/cm

Recommended values given in Table 3

ABSC--Absorption coefficients of irreversibly damaged skin. Coefficients vary with wavelength.

Units: 1/cm

Recommended values given in Table 3

ABSW--Absorption coefficients of water. Coefficients vary with wavelength.

Units: 1/cm

Recommended values given in Table 4

BL(L),L=1,LB--Blood flow rates considered constant in TB layers of tissue of thicknesses TB(L).

Units: g/cm^3-sec

Recommended values: BL(1)=0
BL(2)=0.0118
BL(3)=0

CB--Specific heat of blood.

Units: cal/g-°C

Recommended value: 1.0

CON1,CON2--Constants used to compute thermal conductivity of tissues as function of water content WATER(i,j). Thermal conductivity is given by:

CON1 + CON2 WATER(I,J)/DD(I,J)

where WATER(I,J) = grams of water/cm^3 of tissue
DD(I,J) = density of tissues, g/cm^3

Units cal/cm-sec-°C

Recommended values $CON1 = 1.33 \cdot 10^{-4}$
$CON2 = 1.36 \cdot 10^{-3}$

CUT--Value of normalized gaussian profile at radius RIM.

Units: unitless

DB1,DB2,DB3--Cumulative thermal damage at base of epidermis required to produce first, second and third degree burns respectively.

Units: unitless

Recommended values: DB1 = 0.1
DB2 = 1
DB3 = 10,000

DB5--Temperature of skin required for fifth-degree burns.

Units: °C

Recommended value: 400

DAM(1,1),DAM(1,2)
DAM(2,1),DAM(2,2)--Constants used to compute rates of thermal damage of tissues. Rates of damage are functions of the absolute temperature $\bar{v}$ as described below:

$\exp(DAM(1,1)-DAM(1,2)/\bar{v})$, $317°K \leq \bar{v} \leq 323°K$

$\exp(DAM(2,1)-DAM(2,2)/\bar{v})$, $\bar{v} \geq 323°K$

Units: DAM(1,1) and DAM(2,1), ln(1/sec)
DAM(1,2) and DAM(2,2), °K

Recommended values: DAM(1,1) = 149
DAM(1,2) = 50,000
DAM(2,1) = 242
DAM(2,2) = 80,000

DEPID--Thickness of "dead" epidermal layer.

Units: cm

Recommended value: 0.0060 (half epidermal thickness)

DHF--Depth of hair follicle. If set to unrealistically large value such as 1,000 cm, code will disregard follicle.

Units: cm

Recommended value: 0.215 cm

DPULSC(L),L=1,NPULSE--Durations of each NPULSE coded pulses. Pulses considered back to back and may have any desired power. Power considered constant during each pulse.

Units: sec

DPULSE--Duration of noncoded pulses over which time power is considered constant.

Units: sec

DTEMP--Temperature at base of epidermis causing steam blisters.

Units: °C

Recommended value: 131

D0,D1,D2,D3--Densities of sweat, outer epidermal layer, dermis and subcutaneous tissues, respectively.

Units: g/cm^3

Recommended values: D0 = 1.05
D1 = 0.50
D2 = 1.03
D3 = 0.98

HAIR--Fraction of skin surface shielded by hairs.

Units: unitless

Recommended values: 0 to 0.1

HW--Heat-transfer coefficient associated with heat fluxes across steam blisters.

Units: cal/cm^2-sec-°C

Recommended value: 6.10^{-3}

H1,H2--Heat-transfer coefficients associated with heat losses from dry and wet surface, respectively.

Units cal/cm^2-sec-°C

Recommended values: $H1 = 2.0 \cdot 10^{-4}$
$H2 = 7.0 \cdot 10^{-4}$

ID1,ID2-- Smallest and largest I values at which temperature rises and damage will be printed.

Units: unitless

II1,II2,II3--I indices needed for punching cards for 2 or 3 D temperature illustrations. II1 and II2 represent smallest and largest I indices at which temperatures will be punched respectively. II3 represents curve to be marked in illustrations.

Units: unitless

IPROF--Index indicating shape of beam profiles. Beam profiles assumed to be radially symmetric.

Unit: unitless

Input value: 0 (uniform profile)
1 (gaussian profile)
2 (irregular profile)

ITYPE--Index controlling printing of temperature rises. An ITYPE value of 1 will allow temperatures to be printed following each time step; an ITYPE value of 2 for every other time step, etc. Temperature rises will always be printed following the last time step regardless of the value assigned ITYPE. Additional options for printing are available via the arrays TIME1 and TIME2.

Unit: unitless

JD1,JD2--Range of J indices over which temperature rises and damage will be printed. JD1 represents smallest value while JD2 represents largest value.

Unit: unitless

JJ1,JJ2--Range of J indices over which temperature rises will be punched on cards for preparing temperature illustrations.

Unit: unitless

KTYPE--Index indicating whether or not to punch cards for temperature-rise illustrations. A value of zero will skip cards while a value of 1 will punch cards.

Unit: unitless

Input value: 0 (to skip punching cards)
1 (to punch cards)

KX--Number of time intervals TIME1(L) to TIME2(L) over which printing of temperature rises and damage is allowed.

Unit: unitless

Recommended values: see TIME1(L),TIME2(L)

LASER--Parameter describing whether pulses are noncoded, or coded. Noncoded pulses are identical while coded pulses are not.

Unit: unitless

Input value: 1 (noncoded pulses)
2 (coded pulses)

LB--Number of tissue layers of thicknesses TB(L) used to describe blood flow BL(L).

Unit: unitless

Recommended value: 3, see BL(L),TB(L)

LR--Number of radii RX(L) used to describe relative intensities PX(L) of irregular laser beams.

Unit: unitless

LZ--Number of tissue layers of thicknesses TH(L) used to describe absorption coefficients ABS(L).

Unit: unitless

Recommended value: 3, see ABS(L),TH(L)

M--Total number of axial increments.

Unit: unitless

Recommended values: 15 to 20

MK--Dimension of array DTX(K), POWER(K), or XP(K). Introduced to prevent overflows of storage allowed in dimensioning arrays with time indices, i.e. DTX, POWER and XP.

Unit: unitless

N--Number of radial increments.

Unit: unitless

Recommended values: 15 to 20

NG--Number of groups of pulses, used only with noncoded pulse trains. And then only when selected group of pulses are represented by mean power.

Unit: unitless

NGX--Index indicating whether or not noncoded pulse train is to be treated on a pulse-by-pulse basis, or with mean powers representing specified sets of pulses. Index applies only to noncoded pulses.

Unit: unitless

Input value: 0 (if pulses are to be treated individually)
1 (if some pulses are to be replaced by the mean power)

NPG(L),L=1,NG--Number of pulses contained within each of NG sets of pulses represented by mean power.

Unit: unitless

Input values: see Table 2

NPR(L),L=1,NG--Number of pulses represented by particular individual pulses.

Unit: unitless

Input values: see Table 2

NPULSE--Total number of pulses in pulse train.

Unit: unitless

NTP--Minimum number of time steps assigned to each pulse period.

Unit: unitless

Input value: ~10 for single pulses
2 or more for multiple pulses

NTX--Number of time steps assigned after last pulse. Should be large enough so no further damage occurs.

Unit: unitless

Recommended value: 15 to 20

NW--Number of trials used to approximate rates of heat loss for transforming water into steam.

Unit: unitless

Recommended value: 4; see ZW(L)

N1--Number of uniform radial increments.

Unit: unitless

Recommended value: approximately one-third of N

POWERC(L),L=1,NPULSE--Laser power of successive coded pulses.

Unit: watts/pulse

POWX--Laser power of noncoded pulses.

Unit: watts/pulse

PX(L),L=1,LR--Magnitudes of irregular beam profile at radii RX(L). Values need only be relative. Intermediate values are linearly interpolated between specified points PX(L).

Unit: unitless

REF--Surface reflection at given wavelength WAVEL.

Unit: unitless

Recommended values: see Table 1

REPET--Pulse repetition rate.

Unit: 1/sec

RIM--Radius at which normalized gaussian profile equals CUT. Normalized profiles have an intensity of 1 at the axis of the incident beam.

Unit: cm

RUNIF--Radius of uniform profiles.

Unit: cm

RX(L),L=1,LR--Radii at which magnitude of irregular profiles equals PX(L).

Unit: cm

SHF--Radius of hair follicle. Hair follicle located on axis at depth DHF. Radiant energy totally absorbed by follicle.

Unit: cm

Recommended value: 0.02

SHO--Specific heat of non-water constituents in sweat.

Units: cal/g-°C

Recommended value: 0.22

SH1,SH2--Constants used to compute specific heat of tissues as function of water content WATER(I,J). Specific heat given by:

SH1 + SH2·Water(I,J)/DD(I,J)

where WATER(I,J) = grams of water/cm^3 of tissue
DD(I,J) = density of tissues, g/cm^3

Units: cal/g-°C

Recommended values: SH1 = 0.37
SH2 = 0.63

TB(L),L=1,LB--Thicknesses of LB layers of tissues within which blood flows are considered constant. Blood flows given by BL(L).

Unit: cm

Recommended values: TB(1) = 0.0137
TB(2) = 0.0219
TB(3) = 3.000 (arbitrarily large)

TBL(L),L=1,27--Temperatures at which pressures of confined superheated water equal L atmospheres.

Unit: °C

Recommended values: see Table 5

TDERM--Thickness of dermal layer.

Unit: cm

Recommended value: 0.1779

TE--Temperature of environment.

Unit: °C

Recommended value: 22

TEPID--Thickness of epidermis.

Unit: cm

Recommended value: 0.0121

TH(L),L=1,LZ--Thicknesses of LZ layers of tissues within which absorption coefficients are considered constant. Coefficients given by ABS(L).

Unit: cm

Recommended value: TH(1) = 0.0030
TH(2) = 0.1870
TH(3) = 3.000 (arbitrarily large value)

TIME1(L),TIME2(L);L=1,KX--Start and end of time periods during which printouts of temperature rise are desired. Time measured from start of exposure. For all printouts set TIME1(1)=0, TIME2(1)=10,000 (arbitrarily large time), and KX=1.

Unit: sec

TO--Initial temperature of skin and subcutaneous tissues.

Unit: °C

Recommended value: 37

TSWEAT--Thickness of sweat layer. Sweat layer considered only if it has thickness exceeding the arbitrarily small value of 0.0001 cm.

Unit: cm

Recommended values: 0 to 0.01

WAVEL--Wavelength of laser's radiation.

Unit: μm

W0,W1,W2,W3--Water content associated with sweat, anterior epidermal layer, dermis, and subcutaneous tissues, respectively.

Units: g/cm^3

Recommended values: W0 = 0.95
W1 = 0.20
W2 = 0.80
W3 = 0.05

XC--Factor by which time steps are sequentially increased. Excessively large XC values will cause temperatures to oscillate.

Unit: unitless

Recommended values: 1.1 to 1.4

ZBL--Depth at which steam blister forms, equals thickness of epidermis.

Unit: cm

Recommended values: 0.0121

ZDEP--Depth at which water is prevented from evaporating and may become superheated.

Unit: cm

Recommended value: 0.0060 (half epidermal thickness)

ZR--Factor controlling value of smallest time step.

Unit: unitless

Recommended value: 0.5

ZW(L),L=1,NW--Arbitrary factors used in computing rates of heat loss due to the generation of steam.

Unit: unitless

Recommended value: 1

ZZ--Factor by which minimum time step is altered following each pulse.

Unit: unitless

Recommended value: 1

APPENDIX B

PROGRAM LISTING

- Main Program
- Subroutine TIME
- Subroutine GRID
- Subroutine PROF
- Subroutine CWATER
- Subroutine BA
- Subroutine HTDEP
- Subroutine TEMP
- Subroutine DAMAGE

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```
      **************MAIN PROGRAM*****************
C *** MAIN HANDLES INPUT AND OUTPUT, AND COURSE OF CALCULATIONS
      COMMON AMS(11),AMS(,ALPHA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1B2(35,35),B3(35,35),BL(11),BLDUM(35),[illegible],COM(35,35),CUT,
     2D(35,35),DAM(2,2),DMH,DW,DT,DTS(200),[illegible],DPULSE(50),DTEMP,D2,
     3D0,D1,D2,D3,H,HALN,HH(35),[illegible],IMAX,K,KT,
     4LADEW,LA,LMI,LNJ,LR,LZ,M,MM,MI,[illegible],NPB(30),NPD(30),
     5NPULSE,NTP,NTE,NW,PNW,PROF(200),[illegible](50),PRNT,PR(50),R(35),RR,
     6REP,REPET,RIM,RGV,RN,RUNIF,RZ(50),S(35,35),SMF,SMN,SM1,SM2,TB(11),
     7TDENM,TF,TEPID,TM(11),TMS,TSWEAT,TTIME,V(35,35),VM,VN(35,35),
     8VSM(35,35),WATER(35,35),[illegible],Z(35),ZUL,ZDEP,
     9ZM,ZN,Z=(10),ZZ,DHS,J=
      DIMENSION TML(27),TIME1(10),TIME2(10),VT(-,0,10)
      READ(5,2)LW,ANSW,CON1,CON2,SMF,SM1,SM2,[illegible],N2,N3               1
    2 FORMAT(I7,10E7.3)
      READ(5,3)D0,D1,D2,D3,ZML,WW,DTEMP,DMF,SMF                              2
    3 FORMAT(10E7.3)
      READ(5,4)(TM(L),L=1,LM)                                                3
    4 FORMAT(10F7.4)
      [illegible]D(5,4)CW,(BL(L),L=1,LM)                                     4
      READ(5,4)TSWEAT,DEPID,TEPID,TCENM,TO,TE,ZDEP                           5
      TOL=TO-TE
      READ(5,4)DAM(1,1),DAM(1,2),DAM(2,1),DAM(2,2)                           6
      READ(5,4)(TML(L),L=1,27)                                               7
    7 READ(5,2)LZ,ANSC,N1,N2,WATR,NIF                                        8
      READ(5,4)(TM(L),L=1,LZ)                                                9
      READ(5,4)(ANS(L),L=1,LZ)                                               10
      M=M1
      IF(TSW[illegible].LT..0001)GO TO 10
      M=M2
      DO 8 L=1,LZ
      L1=LZ-L+2
      TM(L1)=TM(L1-1)
    8 ANS(L1)=ANS(L1-1)
      TM([illegible])=TSWEAT
      ANS(1)=[illegible]
      LZ=LZ[illegible]
      DO 9 L=1,LM
      L1=LM-L+2
      TB(L1)=TB(L1-1)
    9 BL(L1)=BL(L1-1)
      TB(1)=TSWEAT
      BL(1)=0.
      LM=LM+1
   10 READ(5,[illegible])IPROF,MK                                            11
   11 FORMAT(10I7)
      IF(IPROF.EQ.1)GO TO 14
      IF(IPROF.EQ.2)GO TO 18
C *** UNIFORM PROFILE
      READ(5,12)RUNIF,N1,N                                                   12,UNIF
   12 FORMAT(F7.4,2I7)
      DR=RUNIF/(N1-.5)
      XO=RUNIF
      GO TO 21
C *** GAUSSIAN PROFILE
   14 READ(5,16)RIM,CUT,N1,N                                                 12,GAUS
   16 FORMAT(2F7.4,2I7)
      XO=RIM*SQRT(-5./ALOG(CUT))
      DR=RIM/N1
      GO TO 21
```

```
C *** IRREGULAR PROFILE
   10 READ(5,11)LR,N1,N                                              10,IRREG
      READ(5,3)(RX(L),L=1,LR)                                        10,IRREG
      READ(5,3)(PX(L),L=1,LR)                                        10,IRREG
      X0=RX(LR)
      DR=X0/N1
   21 READ(5,22)WAVEL,XC,ZR,ZZ,LASER,NPULSE,NSX,NTX                  13
   22 FORMAT(4F7.1,4I7)
      IF(LASER.EQ.2)GO TO 30
C *** NON-CODED LASER PULSES
      IF(NPULSE.GT.1)GO TO 20
      READ(5,3)NTP,DPULSE,POWX                                       14,NC,1
      XX=DPULSE
      GO TO 40
   20 READ(5,3)NTP,REPET,DPULSE,POWX                                 14,NC,2
      XX=(NPULSE-1)/REPET+DPULSE
      IF(NSX.EQ.1)GO TO 26
      DO 25 L=1,NPULSE
      NPS(L)=1
   25 NPR(L)=1
      NS=NPULSE
      GO TO 40
   26 READ(5,11)NS                                                   14,NC,BP
      READ(5,11)(NPS(L),L=1,NS)                                      14,NC,BP
      READ(5,11)(NPR(L),L=1,NS)                                      14,NC,BP
      GO TO 40
C *** CODED PULSES
   30 READ(5,11)NTP                                                  14,CODED
      READ(5,3)(DPULSC(L),L=1,NPULSE)                                14,CODED
      READ(5,3)(POWERC(L),L=1,NPULSE)                                14,CODED
C *** DETERMINE DZ,ZM AND RW
   40 X2=0.
      X4=0.
      L=1
   41 X2=X2+ABS(L)*TH(L)
      X4=X4+TH(L)
      L=L+1
      IF(X2.LT.2..AND.L.LE.LZ)GO TO 41
      READ(5,11)M                                                    15
      IF(LASER.EQ.1)GO TO 44
      XX=0.
      DO 42 L=1,NPULSE
   42 XX=XX+DPULSC(L)
   44 ALPHA=(CON1+CON2*W1/D1)/(SH1*D1+SH2*W1)
      X3=2.*SQRT(ALPHA*XX)
      N3=M+1
      M3=M+1
      ZM=3.0*(X4+X3)
      M1=M
      DZ=(TSWEAT+TEPIN)/M1
      IF(DWF.GT.ZM)GO TO 46
      IF(IPROF.EQ.0)DR=(RUNIF-BWF/2.)/(N1-1.5)
      IF(IPROF.EQ.1)DR=(RIM-BWF/2.)/(N1-1)
      IF(IPROF.EQ.2)DR=(RX(LR)-BWF/2.)/(N1-1)
   46 RW=1.50*(X3+X3)
      READ(5,11)ID1,ID2,JD1,JD2,ITYPE,KTYPE,KK                       16
      ITYPEX=ITYPE
      READ(5,3)(TIME1(L),L=1,KK)                                     17
      READ(5,3)(TIME2(L),L=1,KK)                                     18
      READ(5,3)NN,(ZN(L),L=1,NN)                                     19
```

```
      WRITE(6,48)(Z(L),L=1,NZ)                                      ***
   48 FORMAT(1H ,3HZ=,[illegible])
      READ(5,1)[illegible]                                           20
      WRITE(6,49)[illegible]                                        ***
   49 FORMAT(1H0,[illegible])
      CALL TIME                                                     CALL 1
      CALL [illegible]                                              CALL 1
      CALL PUMP                                                     CALL 1
      IF(NTYPE.EQ.0)GO TO [illegible]
C *** DATA/CARDS FOR 2 [illegible]
      READ(5,11)I11,I12,I13,J11,J12                                  21
      WRITE(1,50)I11,I12,I13,J11,J12                                ***
   50 FORMAT(5I7)
      WRITE(1,50)NZ,NS                                              ***
      WRITE(1,52)(H(J),J=1,NZ)                                      ***
      WRITE(1,52)(Z(I),I=1,NZ)                                      ***
   52 FORMAT(10F7.4)
   55 WRITE(6,56)[illegible]
     1[illegible]
   56 FORMAT(1H ,[illegible]
     1[illegible]
     2[illegible]
     3[illegible]
     4[illegible]
     5[illegible]
     6[illegible])
      WRITE(6,59)IPROF,LABSH,[illegible],NPULSE,[illegible]         ***
   59 FORMAT(1H ,[illegible]
     1[illegible]
     2[illegible])
      WRITE(6,60)[illegible]                                        ***
   60 FORMAT(1H ,[illegible]
     1[illegible])
      IF(IPROF.EQ.0)WRITE(6,64)[illegible]                          ***
   64 FORMAT(1H ,[illegible])
      IF(IPROF.EQ.1)WRITE(6,65)CUTOFF                               ***
   65 FORMAT(1H ,[illegible])
      IF(IPROF.EQ.2)WRITE(6,66)[illegible](HS(L),L=1,NS)            ***
   66 FORMAT(1H ,[illegible]/(1X,10F8.3))
      IF(IPROF.EQ.2)WRITE(6,67)(PS(L),L=1,NS)                       ***
   67 FORMAT(1H ,3HPS=/(1X,10F8.3))
      IF(LABSH.EQ.2)GO TO 72
      WRITE(6,68)DPULSE,NTP,[illegible]                             ***
   68 FORMAT(1H ,7HDPULSE=,F9.3,[illegible],5HPOWER=,E9.3)
      IF(NPULSE.GT.1)WRITE(6,69)(NPS(L),L=1,NS)                     ***
   69 FORMAT(1H ,[illegible]/(1X,10I7))
      IF(NPULSE.GT.1)WRITE(6,70)(NPW(L),L=1,NS)                     ***
   70 FORMAT(1H ,[illegible]/(1X,10I7))
      IF(NPULSE.GT.1)WRITE(6,71)[illegible]                         ***
   71 FORMAT(1H ,[illegible])
      GO TO 78
   72 WRITE(6,74)(DPULSE(L),L=1,NPULSE)                             ***
   74 FORMAT(1H ,7HDPULSE=/(1X,10E8.3))
      WRITE(6,75)(POWER(L),L=1,NPULSE)                              ***
   75 FORMAT(1H ,7HPOWER=/(1X,10E8.3))
   78 WRITE(6,79)ID1,ID2,ITYPE,JD1,JD2,NTYPE                        ***
   79 FORMAT(1H ,[illegible]
     1[illegible])
      WRITE(6,80)(TIME1(L),L=1,NN),(TIME2(L),L=1,NN)                ***
   80 FORMAT(1H ,[illegible]/(1X,10E8.3))
```

```
      WRITE(6,81)(TM(L),L=1,L2)                                         ***
   81 FORMAT(1H ,3HTMO/(1X,10F7.4))
      WRITE(6,82)(AMB(L),L=1,L2)                                        ***
   82 FORMAT(1H ,6HAMBNO/(1X,10F7.0))
      WRITE(6,83)(TM(L),L=1,LM)                                         ***
   83 FORMAT(1H ,3HTMO/(1X,10F7.4))
      WRITE(6,84)(WL(L),L=1,LM)                                         ***
   84 FORMAT(1H ,3HWLO/(1X,10F7.4))
      WRITE(6,85)DAM(1,1),DAM(1,2),DAM(2,1),DAM(2,2)                    ***
   85 FORMAT(1H ,9HDAM(1,1)=,F6.1,2X,9HDAM(1,2)=,F6.0,2X,9HDAM(2,1)=,
     1F6.1,2X,9HDAM(2,2)=,F6.0)
      WRITE(6,86)DH,HH,RZ,ZH,KA                                         ***
   86 FORMAT(1H ,3HDH=,F6.4,2X,3HHH=,F6.4,2X,3HRZ=,F6.4,2X,3HZH=,F6.4,
     12X,3HKA=,I2)
      TTIME=0.
      IMAX=0
      JMAX=0
      LMI=0
      X1=TB+EAT*DEPTD
      X2=TB+EAT+ZDEP
      ZD=0.
      RGV=TOE
      II=1
      HH=TOE
      DO 88 I=1,N3
      IF(X1.GT.Z(I))II=I+1
      IF(X2.GE.Z(I))IP=I+1
      DO 88 J=1,N3
      D(I,J)=1.E-10
      V(I,J)=TOE
   88 VO(I,J)=TOE
C     START OF TEMPERATURE AND DAMAGE CALCULATIONS
C     ----------------------------------------
      KK=1
      K=1
   90 DT=DTZ(K)
      TTIME=TTIME+DT
      POW=POWER(K)
      IF(IMAX.GT.0)CALL CHATER                                          CALL X
      IF(IMAX.GT.0)CALL HA                                              CALL X
      IF(LMI.GE.II)CALL MTDEP                                           CALL X
      IF(K.GT.1)GO TO 105
      WRITE(6,100)                                                      ***
  100 FORMAT(1H ,22HHEAT DEPOSITION RATES=,10H----------)
      WRITE(6,101)(R(J),J=JD1,JD2)                                      ***
  101 FORMAT(1H ,10X,2HR=,9F8.4/13X,30H------------------------------)
      DO 104 I=ID1,ID2
      WRITE(6,102)Z(I),(S(I,J),J=JD1,JD2)                               ***
  102 FORMAT(1H ,2HZ=,F8.4,2X,9E8.3)
  104 CONTINUE
  105 WRITE(6,106)DT,TTIME,POW,XP(K),IMAX,JMAX                          ***
  106 FORMAT(1H0,3HDT=,F8.3,2X,6HTIME=,E9.4,2X,6HPOWER=,E9.3,2X,3HXP=,
     1F5.0,7H  IMAX=,I2,7H  JMAX=,I2)
      CALL TEMP                                                         CALL
      CALL DAMAGE                                                       CALL
      IF(XP(K).LT..99)GO TO 110
      IF(ITYPEX.LT.ITYPE.OR.KK.GT.KX)GO TO 110
      IF(TTIME.LT.TIME1(KK).OR.TTIME.GT.TIME2(KK))GO TO 110
      DO 107 I=ID1,ID2
      DO 107 J=JD1,JD2
```

```
107 VT(I,J)=V(I,J)-TOF
    WRITE(6,101)(R(J),J=JD1,JD2)
    DO 110 I=ID1,ID2
    WRITE(6,108)Z(I),(VT(I,J),J=JD1,JD2)
108 FORMAT(1H ,2X,E10.4,4X,2X,9F8.1)
110 CONTINUE
    ITYPE=0
    IF(NTYPE.EQ.0)GO TO 118
    DO 112 I=II1,II2
    DO 112 J=JJ1,JJ2
112 VT(I,J)=V(I,J)-TOF
    DO 116 I=II1,II2
    WRITE(1,115)(VT(I,J),J=JJ1,JJ2)
115 FORMAT(10F7.1)
116 CONTINUE
    WRITE(1,52)QGV
118 ITYPE=ITYPE+1
119 IF(TTIME.GT.TIME2(KK).AND.KK.LT.K2)KK=KK+1
    IF(V(1,1).GT.ZMX)ZMX=V(1,1)
    K=K+1
    IF(K.LE.KT)GO TO 90
    WRITE(6,122)
122 FORMAT(1H ,7HDAMAGE=,10H----------)
    WRITE(6,101)(R(J),J=JD1,JD2)
    DO 124 I=I1,ID2
    WRITE(6,123)Z(I),(D(I,J),J=JD1,JD2)
123 FORMAT(1H ,2X,E10.4,4X,2X,9E8.2)
124 CONTINUE
    X=1.
    HD=HD+TE
    IF(HD.LT.100.)GO TO 130
    L=2
126 IF(HD.LT.TOL(L))GO TO 128
    L=L+1
    IF(L.LE.27)GO TO 126
128 X1=(HD-TOL(L-1))/(TOL(L)-TOL(L-1))
    X=L-1.+X1
130 WRITE(6,132)X,Z(IQ)
132 FORMAT(1H ,16HPEAK PRESSURE=,F7.1,5H ATM,,3X,6HDEPTH=,F8.4,3H CM)
    VMF=VMF+TE
    IF(ID.EQ.IMF)WRITE(6,133)VMF
133 FORMAT(1H ,37HLOCATED AT MAIN FOLLICLE(TEMPERATURE=,F5.0,3H C))
    JDR=0
    DO 140 J=1,N
    IF(D(II,J).GE.1.)JDR=J
140 CONTINUE
    IF(JDR.EQ.0)GO TO 160
    X1=ALOG(D(II,JDR)/D(II,JDR+1))/(R(JDR+1)-R(JDR))
    X2=R(JDR)+ALOG(D(II,JDR))/X1
    WRITE(6,144)X2
144 FORMAT(1H0,17HRADIUS OF DAMAGE=,F7.4,3H CM)
    DO 150 I=II,M
    IF(D(I,1).GE.1.)IDZ=I
150 CONTINUE
    X1=ALOG(D(IDZ,1)/D(IDZ+1,1))/(Z(IDZ+1)-Z(IDZ))
    X2=Z(IDZ)+ALOG(D(IDZ,1))/X1
    WRITE(6,154)X2
154 FORMAT(1H0,16HDEPTH OF DAMAGE=,F7.4,3H CM)
160 LD=0
    IF(D(II,1).GT.DM1)LD=1
```

```
      IF([illegible]
      IF([illegible]
      IF([illegible]
      IF([illegible]
      WRITE(6,102)[illegible]
  102 FORMAT(1H0,[illegible] OF [illegible])
      STOP
      END
```

```
      ************COMPUTING TIME**************
C *** TIME COMPUTES LASER POWER POWER(N) FOR EACH TIME STEP DTR(N)
      COMMON [illegible]
     1[illegible]
     2[illegible]
     3[illegible]
     4[illegible]
     5[illegible]
     6[illegible]
     7[illegible]
     8[illegible]
     9[illegible]
      DO 2 N=1,NN
      POWER(N)=0.
    2 NP(N)=1.
      [illegible]
      IF(EM.LT.AMP)[illegible]
      [illegible]
      [illegible]
      DTT=DTO
      [illegible]
      [illegible]
      IF(LASER.EQ.2)GO TO 70
C *** NON-CONSTANT PULSE-----------------------------------------
      IF(NPULSE.GT.1)GO TO 31
C *** EXPOSURES INVOLVING A SINGLE PULSE
      DT1=DPULSE/NTP
      IF(DT1.GT.DTO)GO TO 8
      DO 6 N=1,NTP
      DTR(N)=DT1
    6 POWER(N)=POW1
      L3=NTP
      GO TO 30
    8 L1=ALOG(DT1/DTO)/[illegible]
      X1=DTO*(XC**(L1+1.)-1.)/[illegible]
      IF(X1.GE.DPULSE)GO TO 20
      L2=(DPULSE-X1)/DT1+1
      DT1=(DPULSE-X1)/L2
      DO 10 N=1,L1
      DTR(N)=DTT
      POWER(N)=POW1
   10 DTT=XC*DTT
      L2=L1+L2
      L1=L1+1
      DO 12 N=L1,L2
      DTR(N)=DT1
   12 POWER(N)=POW1
      L3=L2
      GO TO 30
   20 X1=2.
   22 X3=EXP(ALOG((DPULSE*X1-DPULSE)/DTO+1.)/L1)
      IF(X3/X1.GT..99999.AND.X3/X1.LT.1.00001)GO TO 24
      X1=X3
      GO TO 22
   24 WRITE(6,26)X3                                                    ***
   26 FORMAT(1H ,3HX3=,F8.4)
      DO 28 N=1,L1
      DTR(N)=DTT
      POWER(N)=POW1
   28 DTT=X3*DTT
```

```
      L3=L1
   29 L1=L3+1
      L2=L3+NTX
      DO 30 K=L1,L2
      DTX(K)=DTO
   30 DTO=XC*DTO
      KT=L2
      GO TO 120
C *** EXPOSURES INVOLVING MULTIPLE PULSES
   31 DTO=DTO/ZZ
      XX2=1./REPET-DPULSE
      XX3=POWX*DPULSE*REPET
      XX4=XX2/(XC+1.)
      K=0
      DO 50 L=1,NG
      DTO=ZZ*DTO
      IF(NPG(L).GT.1)GO TO 40
C  *  SINGLE PULSES
      NP=DPULSE/DTO
      IF(NP.LT.2)NP=2
      XX1=DPULSE/NP
      L2=K+1
      L3=K+NP
      DO 32 K=L2,L3
      DTX(K)=XX1
      POWER(K)=POWX
   32 XP(K)=NPR(L)
      K=L3
      IF(XX4.GT.DTO)GO TO 36
      K=K+1
      DTX(K)=XX4
      XP(K)=NPR(L)
      K=K+1
      DTX(K)=XX2-XX4
      XP(K)=NPR(L)
      GO TO 50
   36 L1=ALOG(XX2*XX5/DTO+1.)/XX6+1.
      DT2=XX2*XX5/(XC**L1-1.)
      L2=K+1
      L3=K+L1
      DO 38 K=L2,L3
      DTX(K)=DT2
      XP(K)=NPR(L)
   38 DT2=XC*DT2
      K=L3
      GO TO 50
C  *  GROUPS OF SEVERAL PULSES
   40 X2=NPG(L)/REPET
      IF(X2.GT.DTO)GO TO 46
      K=K+1
      DTX(K)=X2
      POWER(K)=XX3
      XP(K)=0.
      GO TO 50
   46 L1=ALOG(X2*XX5/DTO+1.)/XX6+1.
      DT2=X2*XX5/(XC**L1-1.)
      L2=K+1
      L3=K+L1
```

```
      DO 48 K=L2,L3
      DTX(K)=DT2
      POWER(K)=XX3
      XP(K)=0.
   48 DT2=XC*DT2
      K=L3
   50 CONTINUE
      L2=K+1
      L3=K+NTX
      DO 54 K=L2,L3
      DTX(K)=DTO
   54 DTO=XC*DTO
      KT=L3
      GO TO 120
C *** CODED PULSES------------------------------------------------------
   70 K=0
      DTO=DTO/ZZ
      DO 100 L=1,NPULSE
      DTO=ZZ*DTO
      DTT=DTO
      DT1=DPULSC(L)/NTP
      IF(DT1.GT.DTO)GO TO 76
      L1=K+1
      L2=K+NTP
      DO 74 K=L1,L2
      DTX(K)=DT1
   74 POWER(K)=POWERC(L)
      K=L2
      GO TO 100
   76 L1=ALOG(DT1/DTO)/XX6+1
      X1=DTO*(XC**L1-1.)/XX5
      IF(X1.GE.DPULSC(L))GO TO 90
      L2=(DPULSC(L)-X1)/DT1+1
      DT1=(DPULSC(L)-X1)/L2
      L3=K+1
      L4=K+L1
      DO 80 K=L3,L4
      DTX(K)=DTT
      POWER(K)=POWERC(L)
   80 DTT=XC*DTT
      L5=L4+1
      L6=L4+L2
      DO 82 K=L5,L6
      DTX(K)=DT1
   82 POWER(K)=POWERC(L)
      K=L6
      GO TO 100
   90 X1=2.
   92 R3=EXP(ALOG((DPULSC(L)*X1-DPULSC(L))/DTO+1.)/L1)
      IF(R3/X1.GT.99999.AND.R3/X1.LT.1.00001)GO TO 94
      X1=R3
      GO TO 92
   94 WRITE(6,26)R3
      L2=K+1
      L3=K+L1
      DO 98 K=L2,L3
      DTX(K)=DTT
      POWER(K)=POWERC(L)
   98 DTT=R3*DTT
      K=L3
```

```
100 CONTINUE
    L3=N+1
    L4=N+NTX
    DO 110 K=L3,L4
    DTX(K)=DTO
110 DTO=XC*DTO
    KT=L4
120 IF(KT.GT.MK)WRITE(6,121)KT
121 FORMAT(1H ,46HNUMBER OF TIME STEPS EXCEEDS DIMENSION MK, KT=,I3)
    IF(KT.GT.MK)STOP
    WRITE(6,122)(DTX(K),K=1,KT)
122 FORMAT(1H ,4HDTX=/(1X,8E9.3))
    WRITE(6,124)(POWER(K),K=1,KT)
124 FORMAT(1H ,6HPOWER=/(1X,8F9.3))
    WRITE(6,126)(XP(K),K=1,KT)
126 FORMAT(1H ,3HXP=/(1X,8F9.0))
    RETURN
    END
```

```
C *** GRID COMPUTES THE RADIAL AND AXIAL SPACE STEPS R(J) AND Z(I)
      COMMON ABS(11),ABSC,ALPHA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1B2(35,35),B3(35,35),BL(11),BLOOD(35),CA,CON1,CON2,CON(35,35),CUT,
     2D(35,35),DAM(2,2),DHF,DR,DT,DTX(200),DPULSE,DPULSC(50),DTEMP,DZ,
     3DD,D1,D2,D3,H,HAIR,HR(35),HW,IA,IHF,II,IMAX,IP,IPROP,IW,JMAX,K,KT,
     4LASER,LA,LM1,LNJ,LR,LZ,M,MK,M1,M3,N,N1,N3,NB,NBX,NPR(30),MPR(30),
     5NPULSE,NTP,NTX,NW,POW,POWER(200),POWERC(50),POWX,PX(50),R(35),RR,
     6REF,REPET,RIN,RSV,RN,RUNIF,RX(50),S(35,35),SHF,SH0,SH1,SH2,TB(11),
     7TDLAM,TE,TEPID,TH(11),TOE,TSWEAT,TTIME,V(35,35),VHF,V0(35,35),
     8VSH(35,35),WATER(35,35),W0,W1,W2,W3,XC,XP(200),Z(35),ZBL,ZDEP,
     9ZM,ZR,ZW(10),ZZ,DRS,JW
      M4=M1+1
      N4=N1+1
C *** CALCULATE STETCH CONSTANT R2
      CK=N3-N1
      CP=RN-(N1-1)*DR
      IF(DHF.LT.ZM)CP=RN-(N1-2)*DR+SHF/2.
      X1=2.
   10 R2=EXP(ALOG((CP*X1-CP)/DR+1.)/CK)
      IF(R2/X1.GT..999999.AND.R2/X1.LT.1.000001)GO TO 13
      X1=R2
      GO TO 10
   13 WRITE(6,14)R2                                                     ***
C *** CALCULATE RADIAL DISTANCES R(J)
   13 R(1)=0.
      R(2)=DR
      IF(DHF.LT.ZM)R(2)=SHF/2.
      DO 15 J=3,N4
   15 R(J)=R(J-1)+DR
      X1=R2*DR
      DO 16 J=N4,N
      R(J+1)=R(J)+X1
   16 X1=R2*X1
C *** CALCULATE AXIAL DISTANCES Z(I)
      Z(1)=0.
      DO 18 I=2,M4
   18 Z(I)=DZ*(I-1)
      DHF=DHF+TSWEAT
      TEPID=TEPID+TSWEAT
      ZBL=ZBL+TSWEAT
      ZM=ZM+TSWEAT
      IHF=0
      IF(DHF.LT.ZM)GO TO 30
C  *  HAIR FOLLICLE NOT PRESENT
      CK=M3-M1
      CP=ZM-(M1-1)*DZ
      X1=2.
   20 R1=EXP(ALOG((CP*X1-CP)/DZ+1.)/CK)
      IF(R1/X1.GT..999999.AND.R1/X1.LT.1.000001)GO TO 23
      X1=R1
      GO TO 20
   23 X1=R1*DZ
      DO 26 I=M4,M
      Z(I+1)=Z(I)+X1
   26 X1=R1*X1
      GO TO 70
C  *  HAIR FOLLICLE PRESENT
   30 LX=(M-M1)/3
      CK=LX+1
      CP=(DHF-TEPID)/2.+DZ
```

```
      X1=2.
   32 R1=EXP(ALOG((CP*X1-CP)/DZ+1.)/CK)
      IF(R1/X1.GT..999999.AND.R1/X1.LT.1.000001)GO TO 34
      X1=R1
      GO TO 32
   34 X1=R1*DZ
      L1=M4+1
      L2=M4+LX
      DO 36 I=L1,L2
      Z(I)=Z(I-1)+X1
   36 X1=R1*X1
      CK=LX
      CP=(DMF-TEPID)/2.
      X1=2.
   42 R1=EXP(ALOG((CP*X1-CP)/SHF+1.)/CK)
      IF(R1/X1.GT..999999.AND.R1/X1.LT.1.000001)GO TO 44
      X1=R1
      GO TO 42
   44 L2=L2+LX
      Z(L2-1)=DMF-SHF
      Z(L2)=DMF
      Z(L2+1)=DMF+SHF
      IMF=L2
      IF(LX.LE.2)GO TO 47
      X1=R1*SHF
      L1=LX-2
      DO 46 I=1,L1
      L3=L2-I-1
      Z(L3)=Z(L3+1)-X1
   46 X1=R1*X1
   47 CK=M3-L2
      CP=ZM-DMF
      X1=2.
   52 R1=EXP(ALOG((CP*X1-CP)/SHF+1.)/CK)
      IF(R1/X1.GT..999999.AND.R1/X1.LT.1.000001)GO TO 60
      X1=R1
      GO TO 52
   60 X1=R1*SHF
      L1=L2+2
      DO 62 I=L1,M3
      Z(I)=Z(I-1)+X1
   62 X1=R1*X1
   70 X1=1000.
      DO 72 I=1,M
      X2=ZBL-Z(I)
      IF(X2*X2.GT.X1)GO TO 72
      IW=I
      X1=X2*X2
   72 CONTINUE
      WRITE(6,88)(R(J),J=1,M3)
   88 FORMAT(1H ,2HR=/(1X,8F9.4))                                   ***
      WRITE(6,90)(Z(I),I=1,M3)
   90 FORMAT(1H ,2HZ=/(1X,8F9.4))                                   ***
      RETURN
      END
```

```
      --------------SUBROUTINE PROF--------------
C *** PROF COMPUTES INTENSITIES OF LASER BEAM AT GIVEN RADII FOR LASER
C *** POWER OF 1 WATT---INTENSITIES IN UNITS OF CAL/CM2-SEC
      COMMON ABS(11),ABSC,ALPHA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1B2(35,35),B3(35,35),BL(11),BLOOD(35),CH,CON1,CON2,CON(35,35),CUT,
     2D(35,35),DAM(2,2),DMF,DR,DT,DTX(200),DPULSE,DPULSC(50),DTEMP,DZ,
     3DO,D1,D2,D3,H,HAIR,HH(35),HHH,IN,INF,II,IMAX,IP,IPROF,IW,JMAX,K,KT,
     4LASER,LR,LMI,LNJ,LW,LZ,M,MR,M1,M3,N,N1,N3,NG,NGX,NPG(30),NPR(30),
     5NPULSE,NTP,NTX,NW,POW,POWER(200),POWERC(50),POWX,PX(50),R(35),RR,
     6REF,REPFT,RIM,RGV,RN,RUNIF,RX(50),S(35,35),SMF,SMR,SM1,SM2,T0(11),
     7TDERM,TE,TEPID,TM(11),TOE,TSWEAT,TTIME,V(35,35),VMF,VO(35,35),
     8VSM(35,35),WATER(35,35),W0,W1,W2,W3,XC,XP(200),Z(35),ZOL,ZDEP,
     9ZM,ZR,ZW(10),ZZ,DMS,JW
      DIMENSION FA(501),FP(501),FX(501)
      LI=500
      DO 10 J=1,N3
   10 HR(J)=0.
      DO 11 L=1,LI
   11 FX(L)=0.
      IF(IPROF.EQ.1)GO TO 44
      IF(IPROF.EQ.0)GO TO 59
C *** IRREGULAR BEAM PROFILE
      RINT=RX(LR)/(LI-1)
C  *  INTEGRATE PROFILE OVER ALL RADII TO DETERMINE QP
      X5=0.
      DO 18 L=2,LR
      X2=(PX(L)-PX(L-1))/(RX(L)-RX(L-1))
      X1=PX(L-1)-X2*RX(L-1)
      X3=X1*(RX(L)*RX(L)-RX(L-1)*RX(L-1))/2.
      X4=X2*(RX(L)*RX(L)*RX(L)-RX(L-1)*RX(L-1)*RX(L-1))/3.
   18 X5=X5+6.2832*(X3+X4)
      QP=.23906*(1.-REF)*(1.-HAIR)/X5
C  *  INTERPOLATE PROFILE AT INTERVALS OF RINT
      L2=2
      X1=0.
      DO 23 L=1,LI
   20 IF(RX(L2).GT.X1)GO TO 22
      L2=L2+1
      IF(L2.LE.LR)GO TO 20
      GO TO 23
   22 X2=(X1-RX(L2-1))/(RX(L2)-RX(L2-1))
      FX(L)=PX(L2-1)+X2*(PX(L2)-PX(L2-1))
   23 X1=X1+RINT
C     CALCULATE TOTAL AREA,FA(L), AND INTEGRAL OF FX(L) WITH RESPECT TO
C     RADIAL AREA,FP(L),FROM R=0 TO VARIOUS RADIAL DISTANCES (L-.5)*RINT
      FP(1)=3.1416*FX(1)*RINT*RINT/4.
      FA(1)=3.1416*RINT*RINT/4.
      DO 34 L=2,LI
      X1=(L-.5)*RINT
      X2=(L-1.5)*RINT
      FP(L)=FP(L-1)+FX(L)*3.1416*(X1*X1-X2*X2)
   34 FA(L)=FA(L-1)+3.1416*(X1*X1-X2*X2)
C  *  CALCULATE PROFILE HR(J) FOR ALL R(J)
      X1=0.
      X2=0.
      DO 35 J=1,N
      X3=(R(J)+R(J+1))/(2.*RINT)+.5000001
      IF(X3.LT.1.)X3=1.0000001
      L2=X3
      IF(L2.GE.LI)GO TO 35
```

```
      X6=XL2
      X5=FP(L2)+X4*(FP(L2+1)-FP(L2))
      X6=FA(L2)+X4*(FA(L2+1)-FA(L2))
      WR(J)=WP*(X5-X1)/(X6-X2)
      X1=X5
      X2=X6
   35 CONTINUE
      GO TO 70
C *** GAUSSIAN BEAM PROFILE
   40 SIGMA=RHOBWHT(-2./ALOG(CUT))
      WRITE(6,46)SIGMA                                                  ***
   46 FORMAT(1H0,6HSIGMA=,E8.3)
      WP=2.0*.2390A*(1.-REF)*(1.-HAIR)/(3.1416*SIGMA*SIGMA)
      DO 47 J=1,N
      X3=2.*R(J)*R(J)/(SIGMA*SIGMA)
      IF(X3.GT.60.)GO TO 47
      WR(J)=WP*EXP(-X3)
   47 CONTINUE
      GO TO 70
C *** UNIFORM BEAM PROFILE
   50 WP=.239006*(1.-REF)*(1.-HAIR)/(3.1416*RUNIF*RUNIF)
      DO 60 J=1,N1
   60 WR(J)=WP
   70 WRITE(6,72)(WR(J),J=1,N)                                          ***
   72 FORMAT(1H ,3HWR=/(1X,8E9.3))
      RETURN
      END
```

```
      ---------------SUBROUTINE CWATER---------------
C *** CWATER COMPUTES CONDUCTIVITIES,HEAT CAPACITIES VERSUS WATER CONTENT
C *** AND BLOOD FLOWS
      COMMON AHS(11),AHSC,ALPHA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1B2(35,35),B3(35,35),BL(11),BLOOD(35),CA,CON1,CON2,CON(35,35),CUT,
     2D(35,35),DAM(2,2),DHE,DH,DT,DTZ(200),DPULSE,DPULSC(50),DTEMP,D2,
     3D0,D1,D2,D3,[illegible],HH(35),[illegible],IN,IMP,II,IMAX,IP,IPHUP,IM,JMAX,K,KT,
     4LABEL,[illegible],M,M1,M3,N,N1,N3,NA,NBX,NPE(30),NPR(30),
     5NPULSE,NTP,[illegible],POWER(200),POWERC(50),POWL,PZ(50),R(35),RR,
     6REP,REPET,RIM,RAV,RR,RUNIF,RZ(50),S(35,35),SHF,SH0,SH1,SH2,TA(11),
     7TDERM,TE,TEPID,TH(11),TM,TSWEAT,TTIME,V(35,35),VHF,VO(35,35),
     8VSH(35,35),WATER(35,35),W0,W1,W2,W3,XC,XP(200),Z(35),ZBL,ZDEP,
     9ZH,ZH,ZW(10),ZZ,[illegible]
      DIMENSION CH(35),DD(35),SS(35),WW(35)
      IF(N.GT.1)GO TO 40
C *** BLOOD FLOWS AT VARIOUS DEPTHS Z(I)
      DO 6 I=1,M
    6 BLOOD(I)=0.
      L1=1
      X1=TH(1)
      I=1
    7 IF(Z(I).LT.X1)GO TO 8
      L1=L1+1
      IF(L1.GT.LM)GO TO 9
      X1=X1+TH(L1)
      GO TO 7
    8 BLOOD(I)=BL(L1)
      I=I+1
      IF(I.LE.M)GO TO 7
C *** DENSITIES DD, WATER CONTENT WW, NON-WATER CONTENT SS AND SPECIFIC
C *** HEATS CH  WITH OR WITHOUT SWEAT
    9 IF(TSWEAT.LT..0001)GO TO 20
      D1=D0
      W1=W0
   20 DO 26 I=1,M
      IF(I.GT.1.OR.TSWEAT.GE.TEPID)GO TO 21
      DD(I)=((D1+3.*D2)*TEPID*TEPID+(6.*D1-2.*D2)*TEPID*TSWEAT+(D1-D2)*
     1TSWEAT*TSWEAT)/(4.*TEPID*(TSWEAT+TEPID))
      WW(I)=((W1+3.*W2)*TEPID*TEPID+(6.*W1-2.*W2)*TEPID*TSWEAT+(W1-W2)*
     1TSWEAT*TSWEAT)/(4.*TEPID*(TSWEAT+TEPID))
      GO TO 23
   21 IF(Z(I).GT.TSWEAT-.0001)GO TO 22
      WW(I)=W0
      DD(I)=D0
      SS(I)=D0-W0
      CH(I)=(SH0*SS(I)+W0)/D0
      GO TO 26
   22 IF(Z(I).GT.TSWEAT+TEPID)GO TO 24
      X1=(Z(I)-TSWEAT)/TEPID
      WW(I)=W1+X1*(W2-W1)
      DD(I)=D1+X1*(D2-D1)
   23 SS(I)=DD(I)-WW(I)
      CH(I)=SH1+SH2*WW(I)/DD(I)
      GO TO 26
   24 IF(Z(I).GT.TSWEAT+TEPID+TDERM)GO TO 25
      WW(I)=W2
      DD(I)=D2
      SS(I)=D2-W2
      CH(I)=SH1+SH2*W2/D2
      GO TO 26
```

```
   26 WW(I)=W1
      DD(I)=D1
      SS(I)=D1-W1
      CH(I)=SM1+SM2*W1/D1
   26 CONTINUE
C *** DETERMINE INITIAL THERMAL CONDUCTIVITIES AND VOLUMETRIC HEAT CAP-
C *** ACITIES
      DO 33 I=1,N3
      WATER(I,1)=WW(I)
      VSH(I,1)=CH(I)*DD(I)
      CON(I,1)=CON1+CON2*WW(I)/DD(I)
      DO 33 J=2,N3
      WATER(I,J)=WW(I)
      CON(I,J)=CON(I,1)
   33 VSH(I,J)=VSH(I,1)
      WRITE(6,30)(CON(I,1),I=1,N3)                                         ***
   30 FORMAT(1H ,4HCON=/(1X,8F9.4))
      WRITE(6,38)(VSH(I,1),I=1,N3)                                         ***
   38 FORMAT(1H ,4HVSH=/(1X,8F9.4))
      RETURN
C *** ADJUST CONDUCTIVITIES AND HEAT CAPACITIES FOR WATER LOSS
   40 DO 44 I=1,IMAX
      DO 44 J=1,JMAX
      DDX=WATER(I,J)+SS(I)
      CHX=(SM0*SS(I)+WATER(I,J))/DDX
      IF(Z(I).GT.TSHEAT-.0001)CHX=SM1+SM2*WATER(I,J)/DDX
      VSH(I,J)=CHX*DDX
   44 CON(I,J)=CON1+CON2*WATER(I,J)/DDX
      RETURN
      END
```

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```
      ************SUBROUTINE MA*****************
C *** MA COMPUTES MATRIX ELEMENTS NEEDED FOR TEMPERATURE COMPUTATIONS
      COMMON [illegible]
     1[illegible]
     2[illegible]
     3[illegible]
     4[illegible]
     5[illegible]
     6[illegible]
     7[illegible]
     8[illegible]
     9[illegible]
      DIMENSION XH1(39),XH2(39),XH3(39),XH4(39),XZ1(39),XZ2(39),XZ3(39),
     1XZ4(39)
      IF(N.GT.1)GO TO 12
      DO 10 J=2,N
      X1=H(J)+H(J-1)
      X2=H(J+1)+H(J-1)
      X3=H(J+1)+H(J)
      XH1(J)=-1./(H(J)*X2)+2./(X2*X1)
      XH2(J)=-1./(X2*X2)
      XH3(J)=2./(X2*X3)+2./(X2*X1)
   10 XH4(J)=1./(H(J)*X2)+2./(X2*X3)
      DO 11 I=2,M
      X1=Z(I)-Z(I-1)
      X2=Z(I+1)-Z(I-1)
      X3=Z(I+1)-Z(I)
      XZ1(I)=2./(X2*X1)
      XZ2(I)=-1./(X2*X2)
      XZ3(I)=2./(X2*X3)+2./(X2*X1)
   11 XZ4(I)=2./(X2*X3)
   12 L1=IMAX-1
      L2=JMAX-1
      DO 23 J=1,L2
      IF(J.LT.JM.AND.IM.EQ.2)GO TO 19
      A1(1,J)=0.
      A2(1,J)=(CON(1,J)+CON(2,J))/(DZ*DZ)+H/DZ+BLOOD(1)*CB/2.
      A3(1,J)=(CON(1,J)+CON(2,J))/(DZ*DZ)
   19 DO 23 I=2,L1
      IF(J.LT.JM.AND.IM.EQ.IM-1)GO TO 23
      IF(J.LT.JM.AND.IM.EQ.IM)GO TO 23
      A1(I,J)=CON(I,J)*XZ1(I)+(CON(I+1,J)-CON(I-1,J))*XZ2(I)
      A2(I,J)=CON(I,J)*XZ3(I)+BLOOD(I)*CB/2.
      A3(I,J)=CON(I,J)*XZ4(I)-(CON(I+1,J)-CON(I-1,J))*XZ2(I)
   23 CONTINUE
      DO 25 I=1,L1
      B1(I,1)=0.
      B2(I,1)=(CON(I,2)+CON(I,1))/(H(2)*H(2))+BLOOD(I)*CB/2.
      B3(I,1)=(CON(I,2)+CON(I,1))/(H(2)*H(2))
      DO 25 J=2,L2
      B1(I,J)=CON(I,J)*XH1(J)+(CON(I,J+1)-CON(I,J-1))*XH2(J)
      B2(I,J)=CON(I,J)*XH3(J)+BLOOD(I)*CB/2.
      B3(I,J)=CON(I,J)*XH4(J)-(CON(I,J+1)-CON(I,J-1))*XH2(J)
   25 CONTINUE
      DO 26 J=1,L2
   26 B2(1,J)=B2(1,J)+H/DZ
      RETURN
      END
```

```
      ***********SUBROUTINE HTDEP*************
C *** HTDEP COMPUTES RATES OF ENERGY DEPOSITION AT EACH GRID POINT PER
C *** UNIT VOLUME OF TISSUE
      COMMON ABR(11),ABSC,ALPHA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1B2(35,35),B3(35,35),BL(11),BLOOD(35),CB,CON1,CON2,CON(35,35),CVT,
     2D(35,35),DAM(2,2),DMP,DN,DT,DTA(200),DPULSE,DPULSE(50),DTEMP,D2,
     3U0,D1,D2,D3,[illegible],HH(35),[illegible],IMAX,IP,IPRUP,IW,JMAX,[illegible],
     4[illegible],L0,LMI,LNJ,LN,L2,[illegible],M1,M3,[illegible],N1,N2,NB,NBT,NPR(30),NPR(30),
     5NPULSE,NTP,NTZ,[illegible],PO,POWER(200),PU,RNE(50),PO,PE(50),R(35),R0,
     6[illegible],NEPRT,NIR,[illegible],RUNIF,RA(50),S(35,35),SMF,SMO,SM1,SMP,TO(11),
     7TDL,[illegible],TF,TEPIC,TH(11),TNE,TR,[illegible],AT,TTIMP,V(35,35),VMF,VO(35,35),
     8VAM(35,35),WATER(35,35),[illegible],X2,[illegible],XC,XP(200),Z(35),ZBL,ZDEP,
     9ZM,ZN,ZM(10),ZZ,DMS,JM
      DIMENSION IE(11),II(36),ZE(11),ZM(36)
      REAL IE,II
      IF(N.GT.1)GO TO 32
      DO 4 I=1,M
      II(I)=0.
      DO 4 J=1,N
    4 S(I,J)=0.
      DO 5 I=1,M
    5 ZM(I)=(Z(I)+Z(I+1))/2.
      IE(1)=1.
      ZE(1)=0.
      L1=LZ+1
      DO 12 L=2,L1
      IE(L)=IE(L-1)*EXP(-ABS(L-1)*TH(L-1))
      IF(IE(L).LT.1.E-10)IE(L)=0.
   12 ZE(L)=ZE(L-1)+TH(L-1)
      II(1)=1.
      L=1
      LX=1
   14 IF(ZM(LX).LT.ZE(L+1))GO TO 16
      L=L+1
      GO TO 14
   16 II(LX+1)=IE(L)*EXP(-ABS(L)*(ZM(LX)-ZE(L)))
      LX=LX+1
      IF(LX.LE.M.AND.II(LX).GT.1.E-10)GO TO 14
      DO 20 I=1,LX
      X2=ZM(1)
      IF(I.GT.1)X2=ZM(I)-ZM(I-1)
      X3=(II(I)-II(I+1))/X2
      DO 20 J=1,N
   20 S(I,J)=X3*HH(J)
      IF(IMF.EQ.0)GO TO 54
      DO 22 I=IMF,M
   22 S(I,1)=0.
      S(IMF,1)=HH(1)*II(IMF)/SMF
      GO TO 54
C *** ADJUST S(I,J) FOR CHANGES IN ABSORPTIVITY
   32 LXX=AMAX1(LX,LMI)
      DO 42 J=1,LNJ
```

```
      DO 34 J=1,LAS
   34 B(I,J)=0.
      XP=Z(I)
      S=1.
      DO 36 I=1,LM1
      IF(XP.LT.Z-1.E-10)GO TO 36
      [illegible]
      IF(I.GT.1)[illegible]
      [illegible]
      IF([illegible])[illegible]
      IF([illegible].LT.1.E-10)[illegible]
      [illegible]
      B(I,J)=[illegible]
      IF(J.EQ.1.AND.I.EQ.[illegible])[illegible]
      [illegible]
   36 CONTINUE
      L1=LM1+1
      IF(L1.GT.LAS)GO TO 42
      DO 37 I=L1,LAS
      IF(XP.LT.Z-1.E-10)GO TO 37
      [illegible]
      IF([illegible].LT.1.E-10)[illegible]
      B(I,J)=[illegible]
      IF(J.EQ.1.AND.I.EQ.[illegible])[illegible]
      [illegible]
   37 CONTINUE
   42 CONTINUE
      IF([illegible].EQ.0)GO TO 54
      DO 44 I=[illegible],N
   44 B(I,1)=0.
      B([illegible],1)=[illegible]
   54 RETURN
      END
```

```
      *************SUBROUTINE TEMP**************
C *** TEMP COMPUTES TEMPERATURES AT EACH GRID POINT ALLOWING FOR EVAPOR-
C *** ATION OF WATER
      COMMON ANS(11),[illegible],A1(35,35),A2(35,35),A3(35,35),B1(35,35),
     1[illegible]
     2[illegible]
     3[illegible]
     4[illegible]
     5[illegible]
     6[illegible]
     7[illegible]
     8[illegible]
     9[illegible]
      DIMENSION CXC(35),DXC(35),FXC(35),CXR(35),DXR(35),FXR(35),JM(35),
     1JBM(35,35),BM(35,35),VS(35,35),VXX(35,35),ZBM(35,35)
      IMAX=0
      JMAX=0
      IF(N.GT.1)GO TO 3
      IAVG=1
      DO 2 I=1,M
      JM(I)=0
      DO 2 J=1,N
      JBM(I,J)=0
    2 BM(I,J)=0.
      X=100.+TE
      VH=TOL
    3 DO 4 I=1,M
      DO 4 J=1,N
    4 VO(I,J)=V(I,J)
      NN=0
C *** COLUMNS(NORMAL)----------------------
    9 DO 45 I=1,M
      DO 44 J=1,N
      W=2.*VSM(I,J)/DT
      FXC(J)=W+A2(I,J)
      IF(J.GT.1)FXC(J)=FXC(J)-A1(I,J)*CXC(J-1)
      CXC(J)=-A3(I,J)/FXC(J)
      SUM=(W-A2(I,J))*V(I,J)-A3(I,J)*V(I+1,J)+PO*B(I,J)-BM(I,J)
      IF(I.GT.1)SUM=SUM-A1(I,J)*V(I-1,J)
      IF(J.EQ.N)SUM=SUM-A3(I,J)*TOL
      DXC(J)=SUM/FXC(J)
      IF(J.GT.1)DXC(J)=(SUM-A1(I,J)*DXC(J-1))/FXC(J)
   44 CONTINUE
      VX=0.
      DO 45 L=1,N
      J=N+1-L
      VX=DXC(J)-CXC(J)*VX
   45 VXX(I,J)=VX
C *** ROWS(NORMAL)-------------------------
      DO 50 J=1,N
      DO 48 I=1,M
      W=2.*VSM(I,J)/DT
      FXR(I)=W+A2(I,J)
      IF(I.GT.1)FXR(I)=FXR(I)-A1(I,J)*CXR(I-1)
      CXR(I)=-A3(I,J)/FXR(I)
      SUM=(W-A2(I,J))*VXX(I,J)-A3(I,J)*VXX(I,J+1)+PRN*B(I,J)-BM(I,J)
      IF(J.GT.1)SUM=SUM-A1(I,J)*VXX(I,J-1)
      IF(I.EQ.M)SUM=SUM-A3(I,J)*TOL
```

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```
      [illegible]
      IF([illegible])[illegible](I)*[illegible](I,J)*[illegible](I+1))/[illegible](I))
   48 CONTINUE
      [illegible]
      DO [illegible] I=1,M
      [illegible]
      [illegible](I)+[illegible](I)*VX
      IF([illegible].LT.[illegible])[illegible]
      IF([illegible].GT.[illegible])GO TO 50
C  * [illegible]
      IF([illegible].LT.[illegible].OR.[illegible](I,J)).LT..0001)GO TO 50
      [illegible](IMAX+1)
      IF(J.GT.JM(I))JM(I)=J
   50 [illegible](I,J)=[illegible]
      IF([illegible].EQ.0)GO TO 60
      [illegible]
      IF([illegible].GT.1)GO TO 52
      [illegible]
      DO 51 I=1,LX
      L1=JM(I)
      DO 51 J=1,L1
      IF([illegible](I,J).GT.(V(I,J)-[illegible])*VSM(I,J)/DT)JSM(I,J)=1
   51 CONTINUE
   52 IF([illegible].GT.[illegible])GO TO 63
      DO 60 I=1,LX
      L1=JM(I)
      DO 60 J=1,L1
      IF(WATER(I,J).LT..001)GO TO 60
      X1=(V(I,J)-[illegible])*VSM(I,J)/DT
      [illegible]WATER(I,J)/DT
      [illegible]SM(I,J)
      IF([illegible].OR.[illegible].GE.[illegible])GO TO 55
      [illegible](I,J)=V(I,J)
      IF(JSM(I,J).EQ.0.OR.[illegible].LT.1.)GO TO 55
      [illegible]*(V(I,J)-[illegible])*ZSM(I,J)/(VS(I,J)-V(I,J))
      IF([illegible].LT.X1)[illegible]=X1
      GO TO 57
   55 [illegible]
   57 [illegible](I,J)=[illegible]
      IF(SM(I,J).LT.0.)SM(I,J)=0.
      IF(SM(I,J).GT.X2)SM(I,J)=X2
      [illegible](I,J)=SM(I,J)-X3
      VS(I,J)=V(I,J)
   60 CONTINUE
      DO 62 I=1,M
      DO 62 J=1,N
   62 V(I,J)=VO(I,J)
      GO TO 9
C *** CORRECT FOR EFFECTS OF WATER LOSS
   63 DO 65 I=1,LX
      L1=JM(I)
      DO 64 J=1,L1
      WATER(I,J)=WATER(I,J)-SM(I,J)*DT/530.
      IF(WATER(I,J).LT..001)WATER(I,J)=0.
      JSM(I,J)=0
   64 SM(I,J)=0.
      JM(I)=0
   65 [illegible]
      IF([illegible].LARGE.[illegible])GO TO 99
      IF([illegible].GT.1.E-10)GO TO 99
C  *  RESET TO SINGLE NON-CODED PULSES TO HANDLE WATER LOSS
      [illegible]
```

```
      KP=NPULSE-L1
      X0=ZH
      IF(ZH.LT.DHF)X0=1.E+10
      X1=AMIN1(DH-DZ,X0)
      DTO=Z/R*X1*X1/ALPHA
      L1=K+1
      DO 72 L2=L1,MK
      POWER(L2)=0.
   72 XP(L2)=1.
      XX2=1./REPET-DPULSE
      XX4=XX2/(XC+1.)
      XX5=XC-1.
      XX6=ALOG(XC)
      LK=K
   74 IF(KP.LT.1)GO TO 82
      K0=LK
      IF(XX4.GT.DTO)GO TO 76
      LK=LK+1
      DTX(LK)=XX4
      LK=LK+1
      DTX(LK)=XX2-XX4
      GO TO 79
   76 L1=ALOG(XX2*XX5/DTO+1.)/XX6+1.
      DT2=XX2*XX5/(XC**L1-1.)
      L2=LK+1
      L3=LK+L1
      DO 78 LK=L2,L3
      DTX(LK)=DT2
   78 DT2=XC*DT2
      LK=L3
   79 DTO=ZZ*DTO
      NP=DPULSE/DTO
      IF(NP.LT.2)NP=2
      XX1=DPULSE/NP
      L2=LK+1
      L3=LK+NP
      DO 80 LK=L2,L3
      DTX(LK)=XX1
   80 POWER(LK)=POWX
      LK=L3
      KP=KP-1
      IF(2*LK+NTX-K0.LT.MK)GO TO 74
      WRITE(6,81)KP
   81 FORMAT(1H ,46HNUMBER OF PULSES TREATED LESS THAN NPULSE, KP=,I3)
   82 L2=LK+1
      L3=LK+NTX
      DO 84 LK=L2,L3
      DTX(LK)=DTO
   84 DTO=XC*DTO
      KT=L3
      NGX=0
C *** ASSESS MAXIMUM TEMPERATURES ACHIEVED, RGV(ANY LOCATION), RB(SUPER-
C ***  HEATED WATER), AND VHF(HAIR FOLLICLE)
   90 DO 92 I=1,M
      DO 92 J=1,N1
      IF(V(I,J).GT.RGV)RGV=V(I,J)
      IF(I.LT.IP.OR.V(I,J).LT.XW)GO TO 92
C *   STEAM CONTAINED
      IF(RB.GT.V(I,J))GO TO 92
      IB=I
```

```
     HHRV(I,J)
  92 CONTINUE
     IF(IMF.GT.0)VMF=AMAX1(VMF,V(IMF,1))
     RETURN
     END
```

```
      **************SUBROUTINE DAMAGE**************
C *** DAMAGE COMPUTES CUMULATIVE THERMAL DAMAGE AT EACH GRID POINT
       COMMON ABS(11),ADC,ALFA,A1(35,35),A2(35,35),A3(35,35),B1(35,35),
      1B2(35,35),B3(35,35),BL(11),BLOOD(35),CH,CON1,CON2,CON(35,35),CUT,
      2D(35,35),DAM(2,2),DHR,DHW,DT,DX(200),DPULSE,DPULSC(50),DTEMP,DZ,
      3DO,D1,D2,DS,H,HAIR,HR(35),HW,IHR,IFF,IT,IMAX,IP,IPROF,IW,JMAX,K,KT,
      4LAST,KL,LR,LMI,LNJ,LR,LZ,M,MK,MI,MS,N,NI,NS,NG,NGX,NPG(30),NPR(30),
      5NPULSE,NIP,NIX,NS,POWER,POWER(200),POWERC(50),POWX,PX(50),R(35),RR,
      6REF,REPET,RIM,RGV,RR,RPT,TE,RX(50),S(35,35),SHE,SHO,SH1,SH2,TH(11),
      7TDERM,TE,TEPID,TH(11),TCF,TS,SEAT,TIME,V(35,35),VHF,VO(35,35),
      8VSM(35,35),WATER(35,35),W0,W1,W2,W3,XC,XP(200),Z(35),ZBL,ZDEP,
      9ZM,ZR,ZR(10),ZZ,DHS,JW
       DO 4 L=K,KT
       IF(POWER(L).GT.1.E-10)KTO=L
     4 CONTINUE
       IF(K.GT.1)GO TO 6
       JW=1
       ZC1=DAM(1,1)
       ZE1=DAM(1,2)
       ZC2=DAM(2,1)
       ZE2=DAM(2,2)
       XD=44.-TE
     6 LMI=0
       LNJ=0
       IF(XP(K).LT..5)GO TO 28
       LL=0
       IF(K.LE.KTO)LL=1
C *** EVALUATE I,J INDICES AT WHICH THERMAL DAMAGE IS OCCURRING
       ID=0
       JD=0
       DO 12 I=1,M
       DO 12 J=1,N
       IF(V(I,J).LT.XD)GO TO 12
       ID=I
       JD=AMAX1(JD,J)
    12 CONTINUE
C *** REVISE MATRIX ELEMENTS IF BLISTER FORMS AT VARIOUS R(J)
       I=IW
       LI=JW
       DO 14 J=JW,N
       IF(V(I,J)+TE.LT.DTEMP)GO TO 14
       IF(IW.GT.2)GO TO 13
       A2(1,J)=(H+2.*HW)/DZ+BLOOD(1)*CH/2.
       A3(1,J)=2.*HW/DZ
       A1(2,J)=2.*HW/Z(3)
       A2(2,J)=2.*HW/Z(3)+(CON(2,J)+CON(3,J))/(Z(3)*(Z(3)-Z(2)))+BLOOD(2)
      1*CH/2.
       A3(2,J)=(CON(2,J)+CON(3,J))/(Z(3)*(Z(3)-Z(2)))
       LI=J+1
       GO TO 14
    13 A1(I-1,J)=2.*CON(I-1,J)/((Z(I)-Z(I-2))*(Z(I-1)-Z(I-2)))
       A2(I-1,J)=2.*CON(I-1,J)/((Z(I)-Z(I-2))*(Z(I-1)-Z(I-2)))+BLOOD(I-1)
      1*CH/2.+2.*HW/(Z(I)-Z(I-2))
       A3(I-1,J)=2.*HW/(Z(I)-Z(I-2))
       A1(I,J)=2.*HW/(Z(I+1)-Z(I-1))
       A2(I,J)=2.*CON(I,J)/((Z(I+1)-Z(I-1))*(Z(I+1)-Z(I)))+BLOOD(I)*CH/2.
      1+2.*HW/(Z(I+1)-Z(I-1))
       A3(I,J)=2.*CON(I,J)/((Z(I+1)-Z(I-1))*(Z(I+1)-Z(I)))
       LI=J+1
    14 CONTINUE
```

```
      JM=L1
      IF(ID.LT.I1)GO TO 28
C *** EVALUATE THERMAL DAMAGE AT EACH GRID POINT OF LIVE TISSUES
      DO 22 I=I1,ID
      DO 22 J=1,JD
      X1=.5*(V(I,J)+VO(I,J))+TI
      IF(X1.LT.44.)GO TO 22
      IF(X1.LT.50.)X2=Z(1)-Z(1)/(X1+273.)
      IF(X1.GE.50.)X2=Z(2)-Z(2)/(X1+273.)
      IF(X2.GT.60.)X2=60.
      X3=EXP(X)*DT*EXP(X2)
      IF(LL.EQ.1)GO TO 20
      IF(D(I,J).LT.1..AND.X3.GT..05)LL=1
   20 D(I,J)=D(I,J)+X3
      IF(D(I,J).GT.1.E+20)D(I,J)=1.E+20
      IF(D(I,J).GE.1.)LMI=AMAX1(LMI,I)
      IF(D(I,J).GE.1.)LNJ=AMAX1(LNJ,J)
   22 CONTINUE
      IF(LL.EQ.0.AND.K.GT.KT+N)*5)KT=K
      WRITE(6,24)LMI,LNJ,ID,JD
   24 FORMAT(1H ,4HLMI=,I3,2X,4HLNJ=,I3,2X,3HID=,I3,2X,3HJD=,I3)
   28 RETURN
      END
```